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Active Phosphoric Acid and its Relation to the Needs of the Soil for Phosphoric Acid in Pot Experiments

BY

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ACTIVE PHOSPHORIC ACID AND ITS RELATION TO THE NEEDS OF THE SOIL FOR PHOSPHORIC ACID IN POT EXPERIMENTS.

BY G. S. FRAPS.

This is a technical bulletin and intended primarily for scientific readers. The conclusions here reported, however, are of considerable popular significance when applied to the soil of Texas, as shall be the object of a later bulletin to explain.

The work here presented falls naturally into two parts. The first part deals with the phosphoric acid in the soil, and attempts to discover the nature of the compounds in the soil from which phosphoric acid is dissolved by weak acid solvents, and the significance of the extracted phosphoric acid to the chemistry of the soil.

The second part deals with an extensive series of pot experiments, and the relation between the results of these experiments, and the analysis of the soil with fifth-normal nitric acid.

By "active phosphoric acid" we mean the phosphoric acid soluble in fifth-normal nitric acid. In using this term in this way we do not intend to convey the idea that the phosphoric acid soluble in fifth-normal nitric acid is all the phosphoric acid of significance to the plant.

FACTORS OF AVAILABILITY OF PLANT FOOD.

The amount of any given plant food which is withdrawn from the soil by the plant does not depend upon one condition only, but is dependent upon and conditioned by a number of the factors. (Fraps, Amer. Chem. Jour. 32, 1904.) These factors may be grouped as follows:

(1) The quantity of the element present at the beginning of the growing season in forms of combination which can be partly or completely absorbed by the plant. This may be called *chemically available* plant food.

(2) The condition of the soil particles. Compounds chemically available may be enclosed in the soil particles so as not to be exposed to the action of plant roots. Such compounds are *physically unavailable.* If the encrusting substance is removed, such bodies become chemically available.

(3) The amount of the plant food transformed during the growing season into forms of combination which can be absorbed by plants. This factor is certainly of importance with respect to

nitrogen; its importance in the case of phosphoric acid and potash is apparently not so great but the matter requires study. This factor may be called *weathering availability.*

(4) The nature of the plant. Plants differ in both their capacity for absorbing food and their need of it. Whatever the cause of these differences, there is no doubt but that they exist. We will call this factor *physiological availability.*

The character of the soil, its chemical composition, the conditions which prevail during the growth of the plant, and perhaps other factors influence the amount of plant food taken up.

METHODS FOR ESTIMATION OF PHOSPHORIC ACID.

The phosphoric acid of the soil is estimated by four groups of methods:

(1) By complete decomposition of the soil, and the estimation of all the phosphoric acid contained therein.

(2) By partial decomposition of the soil with strong hydrochloric acid. This method indicates the wearing qualities of the soil.

(3) By extraction with alkaline solvents. The alkali ordinarily used is ammonia. The phosphoric acid soluble in ammonia has often been called "humus phosphoric acid," and is assumed to be in organic combination and of great importance, but it appears really to come chiefly from the iron and aluminum phosphates.

(4) By extraction with dilute acids. This method is proposed to estimate the phosphoric acid easily taken up by plants, so as to indicate the immediate needs of the soil for plant food. This method is the one under study in this bulletin.

ANALYSIS WITH WEAK ACIDS.

Dyer (Jour. Chem. Soc., 1894, p. 115) found the acidity of the root sap of a number of plants expressed as citric acid, to vary from 0.34 to 3.4, with an average of 0.91 per cent. He accordingly proposed as a solvent to determine the available phosphoric acid of the soil, a 1 per cent solution of citric acid. Applied to Rothamsted soil of known history (Bulletin 106, Office of Experiment Stations, U. S. Department of Agriculture) this solvent gave results in accordance with the productiveness of the plots from which they were taken.

The Association of Official Agricultural Chemists has devoted much time to this method, and modifications of it, and has adopted a provisional method involving the use of fifth-normal nitric acid. It was found that fifth-normal nitric acid gives better results than 1 per cent citric acid.

The bulk of this work has been done with fifth-normal nitric acid.

Correction for Neutralization.—In 1896, the Referee on Soils of the Association of Official Agricultural Chemists pointed out the decrease in the strength of the solvent caused by neutralization by the bases of the soil. As the differences were more markedly in accord with the known history of the soil when correction was made for the acid neutralized by the *two* soils, he recommended that this correction be made, and it was incorporated in the method. Cousins and Hammond (Analyst *28*, 238) found Dyer's method with 1 per cent citric acid unsatisfactory on the highly calcareous soils of Jamaica. If corrected for neutralization, the results agree with the known productiveness.

Wood found that in the soils of India, where correction was made for neutralization, the results were not in accord with the known conditions, but where correction was not made the results agreed.

Dyer, in discussing neutralization, holds that the alkaline condition of the soil is a condition which must decrease the solvent power of the plant, and hence no correction should be made.

Increasing the strength of the acid will increase the quantity of material dissolved by the solvent, and so expose more phosphoric acid to it. Except for highly calcareous soils, which neutralize or nearly neutralize the solvent, I do not believe that correction for neutralization should be made. The bases which enter into solution are not necessarily present in the form of carbonates. Even in calcareous soils, they are in part present as silicates. For these reasons, the author does not practice neutralization.

METHODS OF ANALYSIS.

The following are the methods used by us: Active Phosphoric Acid, Potash, and Acid Consumed.

Weigh 200 gm. soil into a 2¼ liter glass stoppered bottle. Add exactly 2000 c.c. N/5 nitric acid, measured with a flask. Place in a water bath previously heated to 40° C. Digest five hours, shaking every half hour. Filter on a large double folded filter. When cold, take 1800 c.c. for the estimation of phosphoric acid and potash, and save the remainder of the filtrate for "acid consumed." (Wash the residue on the filter thoroughly with distilled water, transfer to drying plates, allow to dry at room temperature and transfer to jars. This is saved for other work.)

Evaporate the 1800 c.c. at first in a large dish on the free flame, then in a small dish on a water bath, add about 10 c.c. hydrochloric acid when nearly dry, evaporate to complete dryness on water bath, and heat to render silica insoluble. Take up residue in water, add

a few drops of hydrochloric acid, and filter into a 100 c.c. flask Make up to volume.

Phosphoric Acid.—Take 50 c.c. for phosphoric acid (do not wash out pipette with liquid, as exactly 50 c.c. must be left). Add 10 c.c. nitric acid, make alkaline with ammonia, then slightly acid If solution is too acid or alkaline results will be poor. Add 10 to 20 c.c. molybdate solution, and digest at a temperature below 40° C. for three hours. Filter and titrate as usual for phosphoric acid Use the 50 c.c. remaining for the estimation of potash.

Potash.—Wash the 50 c.c. reserved above into a porcelain evaporating dish and evaporate once with hydrochloric acid. Dissolve in water and acidify with hydrochloric acid sufficient to take up the basic salts formed by evaporation, and then evaporate with platinum solution after acidifying. Complete as in Moore's method. Protect from ammonia fumes at all times.

Acid Consumed.—Heat 10 c.c. of the filtrate to boiling, boil three minutes, titrate with N/10 NaOH and phenolphthalein. Make a blank on the original nitric acid solution, and calculate the percentage of the acid which was consumed by the soil.

FACTORS INFLUENCING THE COMPOSITION OF THE SOIL EXTRACT

The amount of phosphoric acid extracted from the soil by a given solvent is the difference between that dissolved from the mineral phosphates and that absorbed by the fixing particles of the soil. That is to say, the soil extract does not necessarily represent the solubility of the phosphatic mineral exposed to the action of the solvent, but is the resultant of the solvent and fixative forces. Furthermore, the quantity of phosphate exposed to the action of the solvent depends upon its condition in the soil and the solubility of the protecting material in the solvent used. If the phosphate mineral is enclosed within quartz, it is quite effectually protected from any solvent. If it is contained within zeolites, it may be affected by some solvents and not by others. If it is contained in carbonate of lime, the latter will be dissolved by any acid solvents, with consequent exposure of the included phosphate to the action of the solvent.

The quantity of phosphoric acid contained in the soil extract thus depends upon three factors:

(1) The quantity of phosphate exposed to the solvent, and its solubility under the conditions of the extraction.

(2) The solubility of the soil materials which protect or enclose phosphates.

(3) The power of the soil to fix phosphoric acid under the conditions of the extraction.

The strength of the solvent, its nature, the period of digestion,

the temperature, and the proportion of soil to solvent, all affect the quantity of phosphoric acid contained in the soil extract, but they have their effect through action on the three factors mentioned above.

SOLUBILITY OF MINERAL PHOSPHATES.

The solubility of mineral phosphates which may occur in the soil should throw some light upon the origin of the phosphoric acid in the soil extract.

It is very difficult to decide which phosphatic materials are probably present in the soils. A portion of the phosphoric acid is no longer in the mineral compounds in which it occurs in igneous or other rocks, but has been worked over into other forms, by means of chemical changes, or by passage through plants or animals. We feel justified in saying that the inorganic phosphates are probably present as phosphates of lime, and more or less basic phosphates of iron and aluminum.

A large number of mineral phosphates occur in nature. Some of the more common and abundant minerals were selected for this work, as follows:

Phosphates of Lime.—Apatite, $Ca_3PO_4(ClF)_n$, crystallized tricalcium phosphate with varying amounts of calcium chloride or fluoride, is said to be the form in which phosphoric acid is present in igneous rocks, and it also appears to be present in the soil. Phosphorite, or amorphous phosphate of lime, occurs in limestone, shell rocks, and in large deposits as phosphate rock. These, and precipitated calcium phosphate, were used.

Phosphate of Aluminum.—Wavellite, $4AlPO_4$, $2Al(OH)_3 + 12H_2O$ basic aluminium phosphate, variscite, $AlPO_4 + 2H_2O$ aluminium phosphate, and precipitated aluminium phosphate were used.

Phosphates of Iron.—Vivianite, $Fe_3P_2O_8 + 8H_2O$, or ferrous phosphate, said to occur quite often in clays, triplite, ferrous manganous phosphate; dufrenite, $FePO_4$, $Fe(OH)_3$ a basic ferric phosphate, and precipitated ferric phosphate were used. It is questionable whether ferrous phosphates, such as vivianite or triplite, can exist long in a well-aerated soil.

METHOD OF EXPERIMENT.

The minerals used appeared to be true to name. So far as possible, they were separated from the matrix and were prepared for analysis by grinding to pass an 80-mesh sieve. In most of the work with weak solvents the ratio of soil to solvent is 1 : 10. That is to say, 100 gm. of soil is brought in contact with 1000 c.c.

solvent. In our experiments, such quantity of phosphate was taken as to represent a soil containing a definite amount of phosphoric acid soluble in acids. For example, in most of the experiments, 0.2 gm. phosphoric acid was brought in contact with 1000 c.c. solvent. This would represent 100 gms. of a soil containing 0.2 per cent phosphoric acid.

In all the experiments, unless otherwise noted, the mixture was digested for five hours at 40° C. The solution was filtered, evaporated to dryness, and ignited when necessary, taken up with acid, and phosphoric acid estimated by the volumetric method.

RESULTS OF THE WORK.

Table No. 1 shows the composition of the minerals used for the experiment. The quantity of phosphoric acid taken was based upon the quantity soluble in strong acids, and not upon the total amount present. Based upon the total quantity present, the figures for the solubility of vivianite and wavellite would be lower. Table No. 2 shows the solubility of the minerals and the effect of the nature of the solvent upon the percentage of phosphoric acid dissolved. In this work 0.2 gm. phosphoric acid was brought in contact with 1000 c.c. solvent for five hours at 40° C.

Effect of Nature of Mineral.—Considering first the results with the N/5 nitric acid, for most of the work was done with this solvent, we find that the phosphates of lime are completely soluble, the precipitated phosphates of iron and aluminium are completely soluble, and vivianite and triplite are nearly so. The aluminium phosphates (variscite and wavellite) and the basic ferric phosphates are comparatively slightly dissolved. It is hardly probable that ferrous phosphate (vivianite) is of common occurrence in ordinary cultivated soils, though it may exist in some soils which are not well aerated. *Fifth-normal nitric acid dissolves calcium phosphates completely, but dissolves mineral aluminium phosphates or basic ferric phosphates only to a slight extent. It thus distinguishes between these two classes of compounds in the soil.*

Another conclusion may be drawn from this work. Apatite, phosphate rock, ferric phosphate (precipitated), aluminium phosphate, vivianite, and triplite are practically equally soluble. We also feel justified in saying that acid phosphate would be completely dissolved. But no one yet can claim that these materials possess the same value to plants. *Fifth-normal nitric acid may not distinguish between minerals which have unequal values to plants.* We have no solvent which would dissolve phosphoric acid from the phosphates mentioned in the same proportions as would be taken from them by plants. What we cannot do with known mineral phosphates of known character outside of the soil we could not ex-

TABLE 1.

Composition of Mineral Phosphates.

Laboratory Number.		Phosphoric Acid.		Total insoluble residue.	Silica in insoluble residue.
		In soluble acids.	In insoluble residue.		
236	Aluminum phosphate	35.75	.....	.....	.....
245	Apatite, $3Ca_3P_2O_8+Ca(ClF)_2$	38.70	.....	.....	.....
710	"	39.76	.02	0.97	0.87
727	"	39.55	.08	.....	0.27
237	Calcium phosphate precipitated	43.90	.....	.....	.....
244	Dufrenite, $Fe_4P_2O_{11}+3H_2O$	17.35	0.16	1.72	.....
714	"	29.78	.02	2.26	1.89
728	"	16.40	.82	8.56	0.77
238	Ferric phosphate, precipitated	32.80	.....	.....	.....
239	Phosphorite, $Ca_3P_2O_8+X$	33.10	0.20	7.84	.....
713	"	31.56	.02	3.27	2.95
729	"	34.07	0.25	4.34	4.09
242	Triplite, $(FeMn)_3P_2O_8+(FeMn)F_2$	19.20	0.10	30.61	.....
719	"	36.70	0.20	4.20	2.78
724	"	12.20	3.53	61.12	56.93
716	Variscite,	31.30	2.50	5.84	1.66
732	" $AlPO_4+2H_2O$	5.05	2.83	84.18	82.23
241	Vivianite, $Fe_3P_2O_8+8H_2O$	14.85	0.38	8.06	.....
712	"	22.78	.08	15.00	14.60
733	"	19.10	.20	8.70	6.75
240	Wavellite, $Al_3P_4O_{19}+12H_2O$	10.95	3.86	63.20	.....
721	"	12.20	3.53	61.12	56.93
726	"	10.50	2.03	66.82	65.02

TABLE 2.

Effect of Nature of Solvent Upon Percentage of Phosphoric Acid Dissolved.

Laboratory Number.		1% Citric Acid.	N/5 Hydrochloric Acid.	N/5 Nitric Acid	N/50 Hydrochloric Acid.	N/200 Hydrochloric Acid.
237	Calcium phosphate, precipitated	100	100	.....	100	100
245	Apatite, $3Ca_3P_2O_8+Ca(ClF)_2$	25.5	100	100	47	15.8
710	"	.....	.....	100	.....	.....
727	"	.....	.....	100	.....	.....
239	Phosphorite, $Ca_3P_2O_8$	71	100	100	85	48
713	"	.....	.....	100	.....	.....
729	"	.....	.....	100	.....	.....
236	Aluminium phosphate, precipitated	100	100	.....	100	46.2
716	Variscite, $AlPO_4+2H_2O$	.....	.....	11.7	.....	.....
732	"	.....	.....	1.3	.....	.....
240	Wavellite, $Al_3P_4O_{19}+2H_2O$	3.0	7.5	4.8	4.8	2.4
721	"	.....	.....	4.5	.....	.....
720	"	.....	.....	2.0	.....	.....
238	Ferric phosphate, precipitated	100	100	.....	16.0	8.5
241	Vivianite, $Fe_3P_2O_8+8H_2O$	94.8	100	97.8	36.0	28.0
712	"	.....	.....	98.0	.....	.....
733	"	.....	.....	91.0	.....	.....
242	Triplite	25.0	93.8	99.5	41.2	16.8
719	" $(FeMn)_3P_2O_8+(FeMn)F_2$	.....	.....	97.6	.....	.....
724	"	.....	.....	82.0	.....	.....
244	Dufrenite, $Fe_4P_2O_{11}+3H_2O$	2.0	4.0	1.5	2.0	0.8
714	"	.....	.....	4.8	.....	.....
728	"	.....	.....	8.0	.....	.....

pect to do with the same phosphates after they are put into the soil and with unknown mixed phosphates already within the soil.

Soils may, therefore, contain equal quantities of phosphoric acid soluble in fifth-normal nitric acid, and yet give up unequal quantities of phosphoric acid to plants on account of differences in the phosphates present. This consideration must give rise to caution in comparing the results of all kinds of soils with one another.

Only those soils should be compared which probably contain the same kinds of phosphates. Soils widely dissimilar in origin and character should not be compared, unless there is evidence that they contain similar phosphates.

Effect of Character of the Solvent.—The results secured with solvents other than fifth-normal nitric acid appear in Table 2.

Fifth-normal hydrochloric acid appears to have nearly the same solvent power as fifth-normal nitric acid. *One per cent citric acid* has a somewhat lower solvent power, particularly for apatite and triplite.

Fifth-normal hydrochloric acid is characterized by a much lower solvent power for ferric phosphate, vivianite, and triplite than citric acid. It does not dissolve the calcium phosphates so well as the fifth-normal nitric acid, but to a greater extent than the citric acid.

Two-hundredth-normal hydrochloric acid, as might be expected, falls much lower in solvent power than any of the solvents tested.

We prefer fifth-normal nitric acid to the other solvents. It dissolves the calcium phosphates in the quantity in which they may occur in soils completely, which may not take place with more dilute solvents. It has analytical advantages over citric acid, being much more easily manipulated.

Effect of Ratio of Solvent to Phosphoric Acid.—In the results just discussed, 0.2 gm. phosphoric acid was brought in contact with 1000 c.c. solvent corresponding to a soil containing 0.2 per cent phosphoric acid. Very few soils contain near this amount of phosphoric acid soluble in such weak solvents. For this reason, experiments were made using 0.05 gm. and 0.025 gm. phosphoric acid to 1000 c.c. solvent, corresponding to soils containing 500 and 250 parts per million of phosphoric acid of the kinds in question. The results of these experiments are presented in Table 3.

With fifth-normal nitric acid larger percentages of phosphoric acid were dissolved when the quantity of phosphoric acid was reduced, but the increase was not proportional to the reduction. Not over 10 per cent of the phosphoric acid of basic iron and aluminium phosphates in the soil would be dissolved by this solvent, and probably much less than this percentage.

Fiftieth-normal hydrochloric acid will dissolve nearly all the phosphorite, apatite, or calcium phosphate contained in the soil

when the phosphoric acid in these minerals does not exceed 250 parts per million. Its solvent power for the iron and aluminium phosphates is much less, though it dissolves nearly all the triplite presented to it when containing less than 250 parts per million phosphoric acid. It appears probable than N/50 hydrochloric acid will distinguish more sharply between calcium phosphates and iron and aluminium phosphates than N/5 nitric acid, but at the same time there is danger that all the calcium phosphates may not be dissolved, and this is almost certain to be the case if more than 250 parts phosphoric acid per million is present in these forms.

Two-hundredth-normal hydrochloric acid does not dissolve any of the minerals completely even when only 250 parts per million phosphoric acid is present. For this reason we consider it to be an unsatisfactory solvent.

TABLE 3.

Effect of Ratio of Solvent to Mineral in Percentage of Phosphoric Acid Dissolved.

Laboratory No.		N/5 Nitric Acid.		N/5 Hydrochloric Acid.			N/200 Hydrochloric Acid.		
	Grams of Phosphoric Acid to 1,000 grams solvent	0.200	.025	0.200	.050	.025	0.200	.05	.025
245	Apatite, $Ca_3P_2O_8+Ca(ClF)_2$—percentage dissolved	100			70.3	73.5		31.2	45.3
710	Apatite	100		47.0		97.1	15.8		60.8
727	"	100				100.0			92.9
713	Phosphorite, $Ca_3P_2O_8+4H_2O$	100							95.4
716	Variscite, $AlPO_4+2H_2O$	11.7				12.8			11.3
732	"	1.3	7.2						
240	Wavellite, $AlP_4O_{19}+12H_2O$	4.8	7.5	4.8		5.3	2.4		5.2
726	"	2.0	5.7						
238	Ferric Phosphate			16.0	34.5	37.3	8.5	28.3	25.1
241	Vivianite, $Fe_3P_2O_8+H_2O$	97.8		36.0	59.5	37.2	28.0	23.3	21.9
712	"	98.0				70.7			44.0
733	"	94.0				41.1			28.9
242	Triplite, $(FeMn)_3P_2O_8+(FeMn)F_2$	99.5		41.2	70.5	83.9		29.3	30.9
719	"	97.6				93.3			70.0
724	"	82.0				95.1			66.3
714	Dufrenite, $Fe_4P_2O_43H_2O$	4.8	6.9						
728	"	8.0	9.7						

Effect of Increasing Strength of Solvent.—The analyses of a few solutions made with varying strength of solvent are presented in Table 16. Increasing the strength of solvent does not correspondingly increase the quantity dissolved. In many of the soils, the solvent effect of the stronger acid is not much greater than that of the weaker.

FIXATION OF DISSOLVED PHOSPHORIC ACID.

In the preceding section, it was shown that the phosphates of iron and aluminium are only slightly dissolved by N/5 nitric acid, whereas the phosphates of calcium are completely dissolved. It

should next be ascertained whether the phosphoric acid which enters into solution is removed with the solvent, or whether a portion of it is taken from solution by the fixing materials of the soil.

In order to study this matter, we treated 200 grams of each soil with 200 c.c. of the solvent to be tested. One of these portions received a known quantity of phosphoric acid in the form of potassium phosphate. If no fixation takes place, the quantity of phosphoric acid recovered should be equal to that added, plus that dissolved from the soil. The difference between this quantity and the amount actually extracted represents the amount fixed. The quantities of phosphoric acid used were such as might often be dissolved from the soil. Fixation was found to occur with practically all soils.

TABLE 4.

Phosphoric Acid Absorbed by Soil.

Laboratory Number.		Parts per million of phosphoric acid.		
		With water	N/5 Nitric Acid.	1.8N Nitric Acid.
832	Extract from soil plus phosphoric acid	26.0	48.0	101.0
	Extract from soil alone	2.3	8.5	12.5
	Recovered from soil	23.7	39.5	88.5
	Added phosphoric acid	194.0	194.0	194.0
	Absorbed (parts per million)	170.3	154.5	105.5

Table 4 shows the results of an experiment with water, N/5 nitric acid and 1.8 normal nitric acid, on a soil known to have a high fixing power for phosphoric acid, and shows the method of calculation we used. The soil fixed nearly as much phosphoric acid from the N/5 nitric acid as it did from the water. The fixation is less with 1.8 normal nitric acid, but it is 50 per cent of the added phosphoric acid, showing that even with strong acids a very large amount of phosphoric acid may be fixed.

Table 5 contains the results of a number of experiments. The ratio of soil to solvent in each case was 1 : 10—time, five hours, temperature, 40° C. The absorption ranges from 5 per cent of the added phosphoric acid in the first soil to 94 per cent in the last one. The soils are arranged in the order of their absorptive power from N/5 nitric acid solution.

The absorption from water is greater than from N/5 nitric acid. Where the absorption from water is less than 50 per cent of the phosphoric acid added, the absorption from nitric acid is about one-half as much as from water. The differences are not great where over 75 per cent of the added phosphoric acid is absorbed, the fixa-

tion in the nitric acid solution being somewhat less than from water. We may conclude from these experiments that the *phosphoric acid extracted from the soil by a solvent does not necessarily represent that which goes into solution.*

TABLE 5.

Absorption of Phosphoric Acid from Soils and Composition of Soils.

Laboratory Number.		Percentages of phosphoric acid absorbed from 200 parts per million added.				Composition of soil.			
		Water.	N/5 Nitric Acid.	N/2 Nitric Acid.	1.8N Nitric Acid.	Acid consumed	Lime.	MgO.	Fe_2O_3 + Al_2O_3
176	Norfolk fine sandy loam, Anderson Co.	.....	5	.....	.....	0	.04	.05	1.42
314	Norfolk fine sand, Houston Co.	16	7	0	.....	.....	.10	.05	1.25
179	Norfolk fine sand, Anderson Co.	.....	7.5	.....	.....	.....	.06	.07	1.07
125	Orangeburg fine sandy loam, Lamar Co.	41	14	.....	8	.....	.06	.07	1.62
340	Susquehanna fine sandy loam, Rusk Co.	33	17	.....	17	.....	.06	.11	2.08
821	Orangeburg fine sand, Robertson Co.	38	20	.....	18	2.4	.17	.10	3.08
852	Rice soil from Orange, Texas.	.....	20	.....	.....	.....	.38	.32	5.05
893	Norfolk fine sandy loam, Angelina Co.	46.3	25	.....	.....	.....	.09	.03	2.18
180	Orangeburg fine sandy loam, Anderson Co.	.....	27	.....	.....	0	.02	.04	0.52
178	Orangeburg clay, Anderson Co.	.....	32	.....	.....	10	.23	.22	8.30
103	Houston Clay, Lamar Co.	.....	35	.....	.....	.....	.35	.32	4.43
825	Lufkin fine sandy loam, Delta Co.	75	68	.....	.....	5.0	.42	.40	11.52
332	Houston Clay, Hays Co.	80	70	66	.....	.....	19.32	.44	12.17
336	Susquehanna fine sand, Caldwell Co.	85	75	60	51	.....	.70	.20	15.12
832	Orangeburg clay, Robertson Co.	85	77	.....	53	5.5	0.16	.31	12.81
330	Crawford stony clay, Hays Co.	77	83	.....	60	.....	12.40	.30	16.10
823	Orangeburg fine sandy loam S. S., Robertson Co.	86	94	.....	65	.....	.40	.91	19.22

Relation of Absorption to Composition.—The percentage of the added phosphoric acid absorbed by the soil is related to its content of oxides of iron and aluminium soluble in strong hydrochloric acid. This is brought out in Table 5. The soils are arranged in the order of their increasing absorption of phosphoric acid from N/5 nitric acid solution. Their contents of iron and aluminium are approximately in the same order. Soils containing over 10 per cent of iron and aluminium oxide absorb over 50 per cent of the phosphoric acid presented to them in N/5 nitric acid solution. The two soils containing the largest percentages of oxide of iron and aluminium also possess the highest absorptive power for phosphoric acid.

It need not require a large percentage of fixing material in 100 grams of soil to take up 0.02 grams of phosphoric acid. One-tenth of one per cent of a highly absorptive material should suffice for this purpose. It is, therefore, more surprising that the absorptive power is so closely related to the percentages of oxides of iron and aluminium than that there should be irregularities in these relations. It would appear that only a small per cent of the oxide of iron and aluminium in the soil has a high fixing power, and that

this percentage is comparatively constant, or else the fixing material has only a low fixing power.

The soils with the highest percentages of *lime* did not have the highest fixing power, even from aqueous solution.

Effect of Quantity of Phosphoric Acid on Percentage of Fixation in Acid Solution.—Table 6 shows the effect of different amounts of phosphoric acid on fixation by the soil. In one soil the percentage of fixation decreased with the quantity added. In the other two soils it was nearly constant. The limit of error in using very small quantities of phosphoric acid is so great that it did not appear advisable to carry this line of work further.

In two of the experiments the moist soil was treated with phosphate, allowed to stand forty-eight hours, and then treated with the solvent. In both cases the fixation was slightly increased by standing.

TABLE 6.

Effect of Different Amounts of Phosphoric Acid on Fixation by Soil.

Laboratory Number.		Phosphoric acid added (per million of soil).				
		24	96	240	196	196*
176	Phosphoric acid fixed, per cent	20	11	5	.....	.....
178	Phosphoric acid fixed, per cent	33	36	32	.....	.....
180	Phosphoric acid fixed, per cent	.....	36	23	30	38
103	Phosphoric acid fixed, per cent	.....	.....	.....	35	44
110	Phosphoric acid fixed, per cent	.....	.....	.....	.....	38

Absorption by Soil Residues.—The residues of soils treated with acids have in many cases nearly the same absorptive power for phosphoric acid as the original soils. The soils tested were treated not only with dilute acids at 40°, but with strong acids in the cold. In each case, the residues were washed thoroughly and dried. Fifty grams were brought in contact with 200 c.c. water containing 20 mg. phosphoric acid (400 parts per million of soil) in the form of potassium phosphate and allowed to stand twenty-four hours, being shaken from time to time. The solution was then filtered and 125 c.c. taken for the estimation of the phosphoric acid. The original soil was in all cases treated at the same time and under the same conditions as the residues.

The results of these experiments are presented in Table No. 7. In some of the experiments the time of contact was five hours (Nos. 326 and 336) and in others 40 mg. phosphoric acid was used (Nos. 821, 823 and 825), but these differences are not material to the purposes of the experiments.

TABLE 7.

Percentage of Phosphoric Acid Fixed by Soils and Residues.

Laboratory Number.		Original soil.	N/5 Nitric Acid.	Corrected.	1.8N Nitric Acid.	2/N Hydrochloric Acid.	Corrected.	4/N Hydrochloric Acid.	8/N Hydrochloric Acid.
		1	2	3	4	5	6	7	8
821		19.7	13.8	13.8	19.8	.....	.....	.....	.....
340		32.1	19.9	19.9	12.1	.....	.....	.....	.....
125		35.5	17.8	17.8	17.0	.....	.....	.....	.....
344		41.2	.....	.....	.....	41.6	40.0	44.1	33.1
308		59.3	.....	.....	.....	64.4	62.0	.....	.....
825		71.5	71.4	71.2	73.5	.....	.....	.....	.....
326		81.8	.....	.....	.....	56.1	52.5	57.4	50.8
330		83.0	.....	.....	.....	80.6	58.2	76.1	77.3
336		88.1	.....	.....	.....	89.3	85.7	85.7	59.6
823		96.0	100	88	99.2	.....	.....	.....	.....

Fifty grams of soil were compared with 50 grams of residue. We also corrected the results with the N/5 nitric acid and the 2/N hydrochloric acid to the weight of residue which would be left by these solvents. The results are shown in the table. The correction of soil No. 823 is not accurate, because the absorption could not be over 100 per cent, and the correction was about 13 per cent. Hence it would be impossible to secure a correction which would not cause the residue to appear to absorb less than the original soil.

We find that in the case of the residue from N/5 nitric acid, the residues have a lower absorptive power in three cases, and the same absorptive power in two. When corrected, the absorptive power is lower with soil No. 823, but this correction is not well made, for the reasons already given. While the action of the acid decreases the absorptive power of the soil, the residues still have considerable absorptive power. Considering the 1.8/N nitric acid and the 2/N hydrochloric acid, we find decreased absorption by the residues in five cases, and the same as the untreated soil, or an increase in five. When correction is made to the original weight of residue, we find a decrease in seven cases, and little change in two. One is not corrected. The decrease in one case is only slight. The correction for soil No. 823 is doubtful.

We find, therefore, that while cold strong acids may remove part of the absorptive power of a soil, they may, on the other hand, have little or no effect upon it. This confirms our observation that fixation of phosphoric acid by the soil takes place even in strong acid solution.

Carbonate of lime does not appear to be so effective for fixation as oxides of iron and alumina. If carbonate of lime fixes any phosphoric acid, there is sufficient oxides of iron and alumina to take

up most of this fixed phosphoric acid when it goes into solution when the carbonate of lime is dissolved. This confirms the relation already pointed out between the proportion of fixation and the percentages of iron and aluminium.

Effect of Proportion of Phosphoric Acid Upon Fixation from Water.—In these experiments, 50 grams of soil were treated for twenty-four hours with 200 c.c. of the solution. The solution varied in strength from 207 to 3792 parts per million of the dry soil. The results are presented in Table No. 8. These results are, in most cases, averages of two sets of tests.

The percentage of fixation decreases with the quantity of phosphoric acid, slowly at first and then more rapidly. It is nearly constant when 400 parts per million or less is present.

TABLE 8.

Percentage of Phosphoric Acid Absorbed by Soil.

Laboratory Number.	Parts phosphoric acid per million of soil	207	413	948	1896	3792
		Percentages absorbed.				
341		95.2	95.3	91.5	87.3	68.0
308		61.0	59.3	36.9	28.1	23.1
336		93.1	91.5	72.6	56.4	50.6
336		94.1	87.9	71.7	63.2	48.0
324		80.4	77.5	72.2	74.5	.....

Extraction of Absorbed Phosphoric Acid.—The object of this work was to ascertain how tenaciously the fixed phosphoric acid is held.

Two hundred grams of soil were digested at 40° C. with 200 c.c. N/5 nitric acid. The nitric acid poured upon one portion of the soil contained 200 parts per million of the soil of phosphoric acid in the form of potassium phosphate. At the end of five hours, the solutions were filtered, 1500 c.c. being taken for the estimation of phosphoric acid and silica. The filtrate was measured and its volume recorded. The soil on the filter paper was washed back into the bottle with 2000 c.c. N/5 nitric acid, and again digested. Four treatments in all were made with the acid.

The quantity of phosphoric acid found was corrected for the quantity left in the soil and filter paper by the preceding extraction. The results are presented in Table 9.

Eight soils were examined. The amount of phosphoric acid recovered by the first extraction varied from 5 to 87 per cent, and the total amount recovered by four or six extractions varied from 6.2 per cent to 100 per cent. The quantity of phosphoric acid, as a rule, decreased regularly with each extraction, until it became constant at about the same quantity as the original soil. The effect

TABLE 9.

Extraction of Absorbed Phosphoric Acid.

Laboratory No		1st extraction	2nd extraction	3rd extraction	4th extraction	5th extraction	6th extraction	Total
821	Extracted from original soil, parts per million	7.3	7.3	7.0	5.6	.....	.....	27.2
	Extracted from soil plus 201.3 parts P_2O_5 per million	165.3	17.0	14.6	9.6	.....	.....	206.5
	Percentage recovered of remaining phosphoric acid	79	27	29	22	.....	.....	89
823	Extracted from original soil	6.0	4.7	5.7	6.5	.....	.....	22.9
	Extracted from soil plus 201.3 parts per million of phosphoric acid	17.7	5.5	8.0	5.6	.....	.....	35.4
	Percentage recovered	5	0.4	1.0	.....	.....	.....	6.2
832	Extracted from original soil	76.0	18.4	17.3	14.3	12.1	11.3	.....
	Extracted from soil plus 197.5 per million of P_2O_5	136.5	19.2	18.4	13.1	10.1	11.7	.....
	Percentage recovered	31	1	1	−1	−1	.....	31
852	Extracted from original soil	19.0	10.8	11.0	8.1	.....	.....	48.9
	Extracted from soil plus 201.3 parts per million P_2O_5	161.7	55.8	20.5	11.8	.....	.....	229.8
	Percentage recovered	71	44	30	17	.....	.....	90
1590	Extracted from original soil	10.3	5.8	5.9	5.2	8.5	6.0	.....
	Extracted from soil plus 197.5 per million P_2O_5	171.3	26	18.2	12.5	12.0	13.0	.....
	Percentage recovered	81	56	77	.....	.....	.....	100
1592	Extracted from original soil	36.3	10.5	4.8	4.5	4.8	5.3	.....
	Extracted from soil plus 197.5 per million P_2O_5	208	0.7	10.0	10.2	4.1	5.1	.....
	Percentage recovered	87	.....	.....	.....	.....	.....	88
1121	Extracted from original soil	8.3	6.9	6.8	6.4	7.5	7.1	.....
	Extracted from soil plus 197.5 per million P_2O_5	120.3	21.5	16.7	13.7	11.5	10.5	.....
	Percentage recovered	56	17	14	12	8	7	76
1124	Extracted from original soil	10.7	9.5	9.8	7.0	9.1	7.1	.....
	Extracted from soil plus 197.5 per million P_2O_5	136.7	22.6	20.4	14.3	10.4	10.5	.....
	Percentage recovered	64	17	18	15	3	8	82

of the added phosphoric acid was usually evident in the fourth extraction, and sometimes in the sixth.

With a soil of very high absorptive power (No. 832) the added phosphoric acid had no effect beyond the first extraction, and only 6.2 per cent of the added phosphoric acid was recovered in four extractions.

These observations may be applied to the original soils here studied. Soil No. 821 gives practically the same amounts of phosphoric acid in the first three extractions. As this soil has a low fixing power, we should be justified in saying that it contains prac-

tically no phosphoric acid easily soluble in N/5 nitric acid (calcium phosphate), but all its phosphoric acid is in difficultly soluble forms, of which a portion is given to the acid.

Soil No. 821 contains some calcium phosphate, though the quantity is not large. I should judge that the amount present is about 21 parts per million of phosphoric acid.

Soil No. 823 probably contains all its phosphoric acid in difficultly soluble forms. It may, however, contain as much as 50 to 75 parts per million of calcium phosphate, whose presence is masked by the high fixing power of the soil. We judge, however, that all the phosphoric acid of this soil is present in very difficultly soluble forms.

TABLE 10.

Effect of Proportion of Soil to Solvent in Fixation.

Laboratory No.		400 grams	200 grams	100 grams
823	Milligrams phosphoric acid in 1500 c.c. of solution, without phosphoric acid	1.15	1.4	1.2
	with phosphoric acid	2.18	4.15	10.55
	Parts per million phosphoric acid without phosphoric acid	3.83	9.33	16
	with phosphoric acid	197	197	197
	Total present	200.8	206.3	213
	Found	7.3	27.7	140.6
	Absorbed	193.5	179.6	72.4
	Per cent absorbed	97	90	36

A soil containing phosphates easily soluble in N/5 nitric acid will yield decreasing amounts of phosphoric acid when subjected to successive extractions. The rapidity of the decrease depends upon the fixing power of the soil. *Soils containing little or no phosphates of high solubility, give practically the same amounts of phosphoric acid to successive extractions.* Soils of very high fixing power may give nearly equal amounts of phosphoric acid to successive extractions, whether they contain easily-soluble phosphates or not, provided these phosphates are not present in excessive quantities. We shall refer further to this work in discussing the successive extraction of natural soils with acids. (See page 23.)

Effect of Ratio of Soil to Solvent on Fixation.—This experiment was carried out on soil No. 823, which has high fixing powers. Four hundred, 200 and 100 grams soil were brought in contact with 2000 c.c. N/5 nitric acid five hours at 40°. One portion of each sample received 40 mg. (approximately) of phosphoric acid. The results are presented in Table 10. The percentage of fixation decreased decidedly when the quantity of soil was reduced from 200 to 100 grams.

RELATION OF FIXING POWER OF SOIL TO ABSORPTION FROM FIFTH-NORMAL NITRIC ACID.

By the fixing power of a soil we here mean its power to absorb phosphoric acid from aqueous solution. The method adopted at this Experiment Station for the work on soils is as follows:

Fixing Power of Soils.—Bring 50 grams of the soil in contact with 200 c.c. of a solution containing 20 mg. P_2O_5 (in the form of potassium phosphate). Shake every half hour during the working day, filter at the end of twenty-four hours, measure off 125 c.c., acidify with nitric acid, and evaporate to about 50 c.c. Run five soils and one blank on the solution together. Divide the phosphoric acid found by the quantity added and subtract from 100. Report percentage of phosphoric acid recovered.

In this method, the phosphoric acid offered to the soil is 400 parts per million. For the purposes of this bulletin we define the "fixing power" of a soil as the percentage of 400 parts per million phosphoric acid absorbed under the condition described.

It is important to know whether there is any relation between the fixation of phosphoric acid as determined in this way and the absorption of phosphoric acid from fifth-normal nitric acid solution. If such a relation exists, the estimation of the fixing power of a soil will aid in the interpretation of analyses made with fifth-normal acid.

The results of a number of experiments are presented in Table 11.

The soils are divided into three groups. Group 1 includes soils whose fixing power is less than 50 per cent. We consider these to have a low fixing power. Group 2 includes soils of moderate fixing power, from 50 to 80 per cent. Group 3 includes soils of high fixing power, from 80 to 100 per cent.

The fixation from acid is, as a rule, lower than from water. The relation is variable.

The maximum percentage of fixation from acid in Group 1 is 27.7 per cent. While the decrease caused by fixation in the amount of phosphoric acid dissolved from soils of this group is of some significance, yet we do not consider it of high importance. If we assume that the fixation from acid is 50 per cent of that from water with these soils, we should have a fair aid to our interpretation of soil analyses. The fixation may, indeed, be as much from acid solution as from aqueous solution, but the average would be of assistance. The maximum fixation in Group 2 is 70 per cent, but this is an exceptional soil. The next highest is 41 per cent. Here, the matter of fixation, though of greater importance than in Group 1, and not to be disregarded, is not of prime importance. We can

again assume that the fixation from acid is one-half the fixation from water, or rather one-half the fixing power.

TABLE 11.

Fixation from Water and from Acid.

Soil No.		Percentage from Water 400	Percentage from Acid 200
	GROUP 1:—		
1592		2.6	1.5
174		10.4	7.5
176		14.2	5
314		14.2	7
896		21.1	20
180		22.5	17.5
340		25.0	17
1135		28.0	17.5
125		31.0	14
1586		33.1	11
821		44.8	20.8
1139		45.5	25
	Group 1, average	24.4	13.7
	GROUP 2:—		
1136		52.0	25.7
1152		52.0	26
178		55.8	32.0
834		59.5	21.3
852		60	20
1582		71	35.5
1129		72.8	27
1594		74.6	16.7
1600		75.4	29.6
1124		75.4	37.5
1126		78	39
1121		78	41.4
	Group 2, average	67.0	29.3
	GROUP 3:—		
829		81.7	31.2
332		83.1	70
103		83.7	35.5
1590		84.1	18.5
1587		85.1	30.5
1583		85.2	73
336		86.1	75
330		86.7	83
832		87.1	73
825		88.9	68
1127		94.4	57.1
823		98.2	94
	Group 3, average	87.0	59.1

In Group 3 the fixation from acid varies from 31 to 94 per cent. Six of the soils fix more than 50 per cent of the phosphoric acid, five of them less than 50 per cent. We consider this fixation a matter of great importance in this group of soils. On account of the wide difference between fixation from water and acid no assumption can be made as regards the relation between fixation power and fixation from acid, but direct estimations from acid must be made, with approximately the amounts of phosphoric acid supposed to be present in the soil.

We believe that the determination of the fixing power of a soil for phosphoric acid should always be made in connection with estimation of active phosphoric acid.

Importance of Absorption for Soil Analysis.—We have seen that the extract of a soil with solvents does not represent the solubility of the phosphatic minerals in question, but represents a condition of equilibrium between the solution-tendency and the fixation-tendency of the soil.

If highly soluble phosphates are present in a soil of moderate fixing power, the soil extract will contain less phosphoric acid than is really dissolved, but the amount going into solution will still be greater than the solution-tendency of the fixing materials. The extent of the difference will depend upon the amount dissolved. The phosphoric acid withdrawn from solution will be partly given up again when the soil residue is again treated with the solvent, and the amount going into solution with successive extraction will decrease until it reaches the solubility of the fixed phosphates, when it may remain constant for some time.

A soil of high fixing power may contain a moderate amount of highly-soluble phosphates and yet give no more phosphoric acid to the solvent than if it contained only insoluble soil phosphates. Two soils of this character might be widely different in their content of soluble phosphates, and yet give the same, or nearly the same results to a given solvent.

It is evident that in the analysis of a soil with a weak solvent, we must consider not only the composition of the soil extract, but also the fixing power of the soil. Only by means of these two factors considered together can we gain any idea of the condition of solubility of phosphates in the soil. We will discuss this in detail on a later page, where a discussion of the interpretation of soil analyses is taken up.

SUCCESSIVE EXTRACTION OF NATURAL SOILS.

A number of soils were subjected to successive extractions in the manner previously described (see page 20). The results of this work are presented in Table 12.

TABLE 12.

Phosphoric Acid Extracted from Soils by N/5 Nitric Acid in Parts per Million.

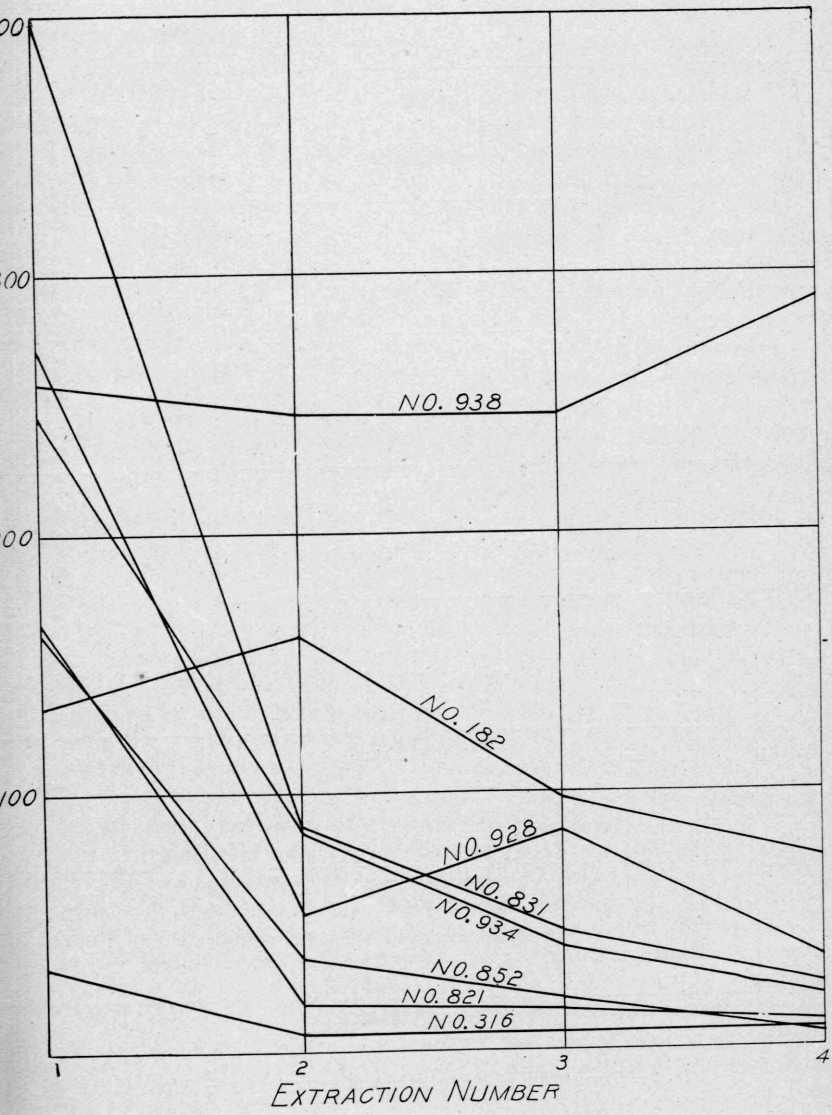
Laboratory Number.	Extraction No.			
	1	2	3	4
831	397	90	47	25
928	271	55	86	34
934	244	86	40	21
938	258	246	246	288
182	132	159	97	74
316	32	6.5	6.5	6.7
821	8	7	6.5	6.0
823	5	6.5	5.5	6.1
852	18	11	9.8	7.3
896	30	7.7	7.8	7.0

The phosphoric acid removed falls off rapidly with successive extractions, and shows a tendency to become constant at about seven parts per million of soil. Soil No. 938 gives nearly constant quantities of phosphoric acid, but this fact is explained when we consider the acid consumed in the successive digestion:

	Acid Consumed, Per Cent.
Digestion No. 1	99.5
Digestion No. 2	99.5
Digestion No. 3	90.5
Digestion No. 4	44.5

The constant amount of phosphoric acid is thus given up by the solution of a constant amount of lime. The phosphoric acid dissolved by successive extractions from soils containing moderate amounts of phosphoric acid, closely resembles that dissolved from the fixed phosphoric acid (see Table 9). The curves made by plotting the results are very similar. (See Fig. 1.)

It was pointed out by Hall and Amos that the phosphoric acid extracted from the fertilized plots at Rothamsted by successive extractions with citric acid, when plotted, forms a logarithmic curve. Only the plots which had been continually receiving the same superphosphate manure show this logarithmic rate of decrement in the amounts of phosphoric acid going into solution. They add, "It can hardly be doubted, however, that the logarithmic portions of the curves represent a single phosphoric acid compound in the soil, which has been almost wholly removed after the third extraction, and that the non-logarithmic character of the curves yielded by the other soils indicates that their phosphoric acid is present in a more varied and irregular state of combination, as, indeed, would be expected from the treatment or the history of the plots." (*Hall and Amos, Transactions of the Chemical Society, 1906, p. 215.*)



. Phosphoric Acid by $\frac{N}{5}$ Nitric Acid (No. 821 and No. 852 with added Phosphoric Acid.)

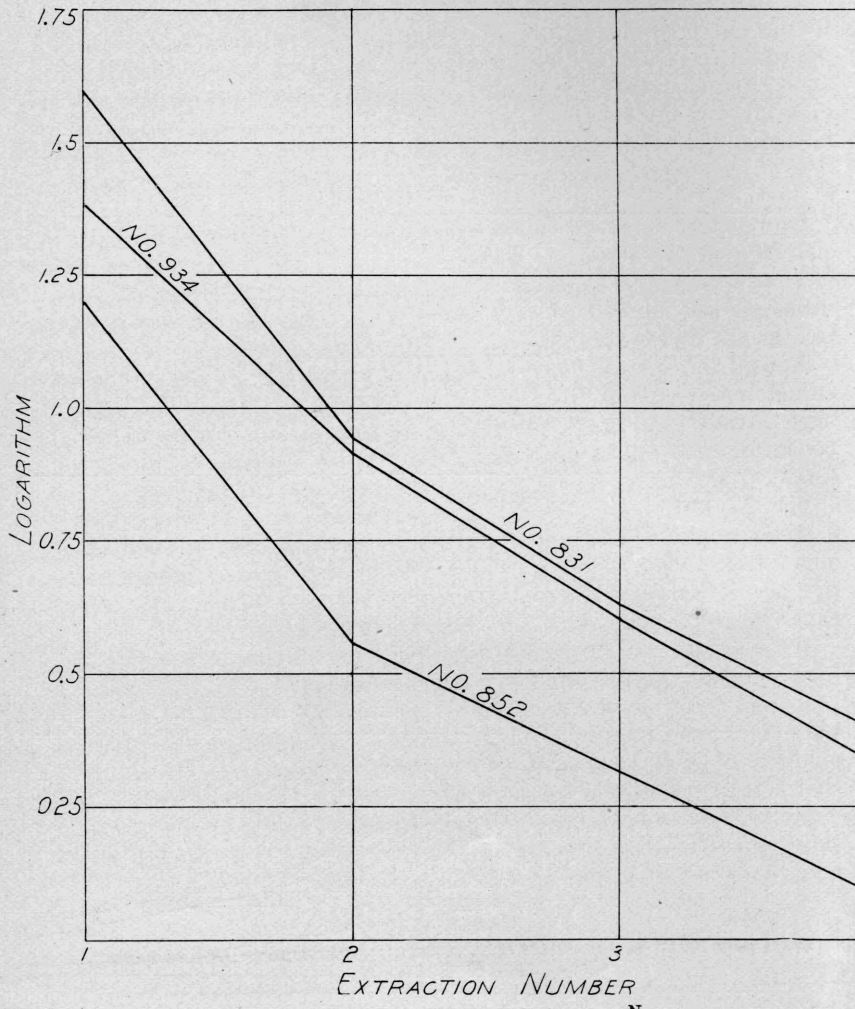


Fig. 2.— Logarithms of Phosphoric Acid extracted by $\frac{N}{5}$ Nitric Acid.

The curves yielded by a number of our natural soils are logarithmic curves, as shown by Fig. 1 and 2. Soils 821 and 852 do not represent natural soils, but are soils which received an addition of potassium phosphate.

It will be observed that the curves of the natural soils are similar to the curve of the natural soil plus potassium phosphate. This points to the truth of the statement of Hall and Amos referred to above, namely, that the logarithmic curve indicates the presence of a more easily soluble phosphate. Our experiments go to show, however, that this phosphate is not completely extracted by the first three extractions, but its effects may persist for six or more extractions.

Our experiments also make clear the cause of the logarithmic character of the curve—it is due, namely, to the fixing properties of the soil. This fixing power varies with different soils, and will influence the amount of phosphoric acid extracted by successive treatments, and hence the exact nature of the curve.

Not all the curves shown in Fig. 1 approach the nature of logarithmic curves. Soil No. 938 presents nearly a straight line. We have already explained these results as due to the quantity of carbonate of lime present—enough to neutralize the acid in the first three extractions.

Soil No. 316 represents a common type of curve, in which only a small quantity of soluble phosphoric acid is present, and the amount extracted is nearly constant after the first extraction. A number of soils would give a similar curve (see Table 14). The cause of the deviations of No. 928 is not known.

We may consider it established that soils contain phosphates of high solubility in N/5 nitric acid, and phosphates of low solubility; that the fixing power of the soil prevents all the highly-soluble phosphoric acid appearing in the extracts, but causes a decreasing quantity of phosphoric acid to be present in successive extractions; that after a number of extractions the quantity of phosphoric acid extracted tends to become constant. It would appear that this constant quantity should be about 7 parts per million, though this quantity was not reached in all our extractions.

TABLE 13.

Extraction With Various Strengths of Acid. (Phosphoric Acid in Parts per Million.)

	Extraction No.					
	1	2	3	4	5	6
Soil No. 831—N/2 Nitric Acid	569	121	39.6	29.3	22.6	19.6
2N Acid	646	117	33.6	32.5	23.0	25.3
Soil No. 928—½ N. Acid	1427	123	55.0	34.7	29.0	20.2
2N Acid	1527	214	51.6	38.7	25.3	24.6
Soil—N/2 N Acid	909	269.6	65.6	23.6	21.0	15.3
2N Acid	896	120	25	28.3	19.1	21.0

Successive Extraction with Strong Acids.—Table 13 shows the results of extraction with two strengths of nitric acid. The results are similar to those secured with N/5 nitric acid. Somewhat more phosphoric acid is secured by the stronger acid with the first extraction, but the results of the succeeding extractions are very close together.

Table 14.

Effect of Strength of Solvent on Extraction of Phosphoric Acid

Laboratory Number.	Water	N/5 Nitric Acid	N/2 Nitric Acid	1.8N Nitric Acid
340	11	13	.....	34
125	1	8	.....	22
330	4	31	.....	506
332	0	11.7	62	.....
336	2	5	5	6
314	5	18	25	.....
825	0	8.5	.....	.....
832	2.3	8.5	.....	12.5
821	0	6.5	.....	23.0
823	1	10.5	.....	43.5
895	3.5	19.5	.....	46.5

EFFECT OF STRENGTH OF SOLVENT.

Table 14 shows the phosphoric acid secured by extraction with water, N/5 nitric acid, and other solvents. The amount of phosphoric acid increases with the strength of the solvent. The additional phosphoric acid secured by the stronger acid comes from the more insoluble phosphates, and not from the easily soluble phosphates.

EFFECT OF SULPHATE OF LIME.

The effect of sulphate of lime upon several soils was studied. Soils were selected which are high in iron, as it was found in previous work by the writer (Amer. Chem. Journal 23, 1, 1904) that sulphate of lime increased the amount of phosphoric acid which went into solution and also increased the amount of iron dissolved.

In these experiments, one gram of sulphate of lime was added to 100 grams soil and the soil extracted with N/5 nitric acid. At the same time, an extraction was made without the sulphate of lime. (See Table 15.) The soils, in all cases, gave darker solutions when treated with sulphate of lime, indicating a larger solution of iron. The results of the experiments show that the sulphate of lime increases the solvent action of the nitric acid, both for iron and for phosphoric acid. The difference is probably due to the increased solubility of the basic phosphates of iron. We do not attach any

great importance to this matter, for very few soils contain appreciable amounts of sulphate of lime.

TABLE 15.

Effect of Sulphate of Lime Upon Phosphoric Acid Dissolved by N/15 Nitric Acid. (Phosphoric Acid in Parts per Million.)

Laboratory Number.	No addition.	Sulphate of lime added.
823	7.21	5.0
829	23.5	41.3
1078	57.5	61.0
1127	13.1	23.5
832	14.3	33.3
1129	11.3	18.5

The only significant point is, whether the addition of sulphate of lime would make phosphoric acid available. The sulphate of lime increased the dissolving action of the nitric acid, but this is no evidence that it has changed the form of combination of the phosphates, or that it would increase the solvent action of the roots upon such phosphates.

SOLUBILITY OF CONSTITUENTS OF THE SOIL.

The solubility of the constituents of the soil must be considered as a factor in the analysis of soils with weak solvents. If any quantity of the soil passes into solution, phosphates will be exposed to the action of the solvent which were protected from the action of soil moisture and roots, and which are really *physically unavailable.* This factor must be given careful consideration. For example, N/5 nitric acid dissolves 320 parts per million of lime (CaO) from soil No. 176, while from soil No. 938 it dissolved 53,250 parts, which corresponds to nearly 10 per cent carbonate of lime. The amount of phosphoric acid brought into action through the solution of the lime in the soil first named may not be large, but in the case of the second soil, 10 per cent of the soil enters into solution, and all the phosphoric acid protected within this 10 per cent is exposed to the action of the solvent. This action is further emphasized, in the case of the soil just mentioned, by the fact that a second treatment with acid dissolves 43,400 parts per million of lime additional, and a third treatment dissolves 46,360 parts, making a total of about 14 per cent of lime dissolved from the soil, corresponding to about 25 per cent carbonate of lime.

This soil, of course, represents an extreme instance, but it emphasizes the difference between a calcareous and a non-calcareous soil. In a non-calcareous soil, the phosphoric acid inclosed within the soil particles is protected from the solvent, while in a cal-

careous soil, that portion of the phosphates included in the calcareous matter dissolved by the acid is exposed, and may be dissolved.

Since the phosphoric acid dissolved from a non-calcareous soil is present on the external surface of the soil grains, and accessible to the roots of the plants and the action of soil moisture, while that dissolved from calcareous soils is without doubt, in part included within the soil grains, and not accessible to plant roots, it is obvious that calcareous soils may contain a larger quantity of active plant food than non-calcareous soils, and yet require fertilization with phosphates on account of the phosphoric acids being protected.

Two calcareous soils may also contain the same amount of active plant food, and yet differ in the amount plants can take from them. In one the phosphates may be on the extreme surface of the soil grains, in the other it may be disseminated through them.

Calcareous soils are more *durable* than non-calcareous soils. This may be explained by the fact that the gradual weathering of such soils continually exposes fresh surfaces of phosphatic minerals. There are other causes for this fact, however.

"Acid Consumed."—The acid consumed in digesting a soil with N/5 nitric acid (or with other acids) may be easily determined, and may serve as an approximate measure of the quantity of lime and magnesia which enters into solution.

Our custom has been to express the amount of acid consumed in percentage of that used. For example, if 10 c.c. of the acid requires 20 c.c. caustic soda to neutralize it before digestion, and 18 c.c. afterwards, then the acid consumed is 10 per cent. Phenolphthalein is used as an indicator, so that the acid consumed corresponds to lime and magnesia, and does not include iron and aluminium.

The following table shows the percentages of lime calculated from acid consumed. The ratio of soil to acid is 1 : 10, and the acid is N/5.

TABLE 16.

Bases Corresponding to Acid Consumed.

Per cent acid consumed.	Equivalent to per cent lime (CaO) dissolved from soil.	Corresponding per cent of carbonate of lime.
5	0.28	0.50
10	0.56	1.00
20	1.12	2.00
50	2.80	5.00
100	5.60	10.00

The method for the estimation of the acid consumed is described as follows: Digest 10 gm. soil for five hours at 40° with 100 c.c. N/5 nitric acid. Filter. When cold, measure off 10 c.c., heat to boiling, boil three minutes at least, and titrate with N/10 caustic

soda and phenolphthalein. Make a blank on the original nitric acid solution, and calculate the percentage of acid which was consumed by the soil.

This determination is usually made in connection with the estimation of the phosphoric acid (and potash) soluble in N/5 nitric acid, a portion of the filtrate being used for acid consumed.

Importance of Acid Consumed.—The "acid consumed" is an index of the amount of lime and magnesia dissolved by the nitric acid, and shows the amount of this material through which the phosphoric acid extracted from the soil may have been diffused.

For example, take two soils containing 50 parts per million of phosphoric acid. Suppose one consumes 1 per cent of the acid, the other 50 per cent. In the first soil, practically all the phosphoric acid is upon the external surface of the soil grains, and accessible to plants. In the second soil, the 50 parts per million of phosphoric acid may be distributed through the equivalent of 50,000 parts per million of carbonate of lime. How much of the phosphoric acid may be exposed to plant roots in the latter case depends upon the manner of distribution of the phosphoric acid and the size of the soil particles. With the same distribution, the smaller the soil particles, the greater the exposed surface.

Percentages Dissolved by Weak Solvents.—Table 17 shows the percentages of silica, oxides of iron and alumina, lime and magnesia dissolved from certain soils by N/5 nitric acid. There are considerable differences between the various soils. Silica varies from .015 to 0.44 per cent; oxides of iron and alumina from 0.04 to 1.39; lime from .009 to 5.32, and magnesia from 0.016 to 0.19. The acid consumed varies from 0 to 100 per cent. The greatest and most significant variation is with the lime. The silica shown in the table is that actually dissolved by the solvent. That which was set free, but remained undissolved, was not determined.

Table 18 shows the quantity of oxides of iron and alumina, lime, and magnesia dissolved by weak solvents expressed in percentages of the quantity dissolved by hydrochloric acid of 1.115 specific gravity (A. O. A. C. methods).

It is evident that considerable variation exists between the solubility in weak solvents of the constituents of various soils. It is evident that, since the dissolved material may contain, or protect, plant food, which thus is not exposed to the action of roots, a factor of considerable complexity is introduced into our interpretation of the analyses of soils with weak solvents. It is evident that this factor cannot be disregarded, but must be studied, and valued.

TABLE 17.

Percentages Dissolved by N/5 Nitric Acid.

Laboratory Number.	Dissolved silica	Oxides of iron and alumina	Lime	Magnesia	Acid consumed
125	0.21	0.11	.09	.018	.....
326	.44	1.39	1.40	.06	.....
336	.18	.58	.34	.04	.....
831	.32	.48	2.76	.19	50.4
844	.12	.27	.53	.04	9.5
845	.13	.33	.51	.21	12.5
928	.25	.60	2.62	.18	27
934	.30	.47	2.59	.13	92.5
938	.06	.11	5.32	.12	99.5
176	.015	.04	.032	.03	0
178	.090	.31	.26	.03	10
180	.030	.10	.08	.03	0
103	.084	.46	.26	.016	.....
110	.12	.42	4.36	.016	.....
Maximum	0.44	1.39	5.32	0.18	100
Minimum	0.015	.04	0.009	0.016	0

TABLE 18.

Material Dissolved by N/5 Nitric Acid in Percentage of that Dissolved by Strong Hydrochloric Acids.

Laboratory Number.	Oxides of iron and alumina	Lime	Magnesia
125	7	15	25
326	9	89	7
336	4	49	20
831	5	88	19
844	5	82	13
845	3	100	42
176	3	8	6
178	4	100	14
180	3	100	40
103	10	74	5
110	7	77	2
Maximum	10	100	42
Minimum	3	8	2
Average	5.5	72	18

Apparently, it is of the greatest importance in connection with calcareous soils. At all events, the difference between calcareous and non-calcareous soils is most marked. But we are not yet ready to state that the differences between the amounts of silicates decomposed, and of iron and alumina dissolved may not be of great importance in comparing different soils. Suppose, for the sake of comparison, we assume that the dissolved material contains 1 per cent of phosphoric acid. Then for each 0.01 per cent dissolved, 1 part per million of phosphoric acid would be exposed to the solvent. Then the phosphoric acid exposed by solution of iron and

alumina in the eleven soils studied (Table 12) would vary from 4 to 139 parts per million; that exposed by the solution of the lime, from 3 to 532 per million; by the magnesia from 2 to 18. It is thus evident that the differences might be considerable, and that two soils might expose the same amount of the same kind of phosphates to the plant roots and yet give up very different amounts to an acid solvent, or they might expose different amounts, and yet give up nearly the same quantities.

It is at present impossible to make any correction for the phosphoric acid exposed by the solvent action of the soil constituents. It is a matter which must be carefully considered in connection with soil analyses.

TABLE 19.

Material Dissolved by Successive Extractions in Parts per Million.

Laboratory uumber of soil	831	844	845	928	934	938
Fe_2O_3, Al_2O_3, P_2O_5:						
First extraction	4,820	2,670	3,370	6,010	4,700	1,060
Second extraction	5,000	1,390	3,940	3,910	4,880	3,990
Third extraction	2,940	1,080	2,870	2,750	2,770	4,830
Fourth extraction	2,250	1,010	1,930	2,050	2,080	2,150
CaO:						
First extraction	27,633	5,318	5,174	26,165	25,924	53,249
Second extraction	3,675	663	700	1,913	3,297	43,406
Third extraction	370	218	843	469	1,063	46,364
Fourth extraction	259	181	173	181	251	24,568
MgO:						
First extraction	1,947	417	2,106	1,764	1,329	1,156
Second extraction	526	170	308	736	580	1,000
Third extraction	188	199	431	427	319	315
Fourth extraction	329	178	174	348	279	544

Effect of Successive Extractions.—The amounts of material dissolved by successive extractions with N/5 nitric acid is shown in Table 19. It is evident that the quantity dissolved by the second extraction may be large, and may continue large for several successive extractions. That is to say, new protecting material may be removed and expose new quantities of phosphoric acid to the dissolving medium. This is especially the case if the acid is nearly or completely neutralized during the previous extraction. In such event a large amount of lime may enter into the second extract. All the material dissolved is less in subsequent extractions. The decrease is more rapid when large quantities are dissolved by the first extraction. There appears a tendency towards constancy, the silica at about 500 parts per million, the iron and alumina at 2000(?), the lime at 200, and the magnesia at about the same. This statement applies only to the soils studied (see the table).

The silica and oxides of iron and alumina fall off slowly to about one-third in the fourth extraction. The amounts of lime and magnesia extracted decrease rapidly. Such would not be the case with soils containing less soluble calcium salts.

Table 20 shows the quantity of material removed from two soils

by successive extraction with N/2 and 2 N nitric acid. The differences between the amount of material extracted by the two solvents are not as great as one would expect. There is exhibited the same tendency that was observed with the weaker solvent towards a slow falling off in the iron and alumina dissolved, and a rapid falling off in the quantities of lime and magnesia dissolved.

It would appear that lime and magnesia are present in the soil (a) as highly soluble compounds, such as carbonates; (b) as moderately soluble silicates, and (c) silicates of low solubility. The iron and alumina compounds differ in solubility, but much less than the lime compounds.

TABLE 20.

Extracted by Successive Digestions with Nitric Acid in Parts per Million.

Laboratory number of soil	831		928		938	
	2N	N/2	2N	N/2	2N	N/2
Oxide of iron and alumina:						
First extraction	8,390	5,530	9,290	5,750	5,240	1,810
Second extraction	5,240	4,130	5,670	4,040	3,090	1,830
Third extraction	2,880	1,910	3,160	2,380	970	1,190
Fourth extraction	3,820	3,340	4,430	3,270	1,640	1,490
Fifth extraction	4,200	3,260	3,680	3,190	1,280	1,270
Sixth extraction	5,320	3,360	3,520	2,850	1,190	1,020
Lime:						
First extraction	22,958	22,653	22,699	10,705	119,478	94,267
Second extraction	4,381	3,605	1,321	707	44,920	1,072
Third extraction	576	699	393	452	3,616	914
Fourth extraction	395	325	358	333	349	526
Fifth extraction	86	185	lost	214	193	218
Sixth extraction	181	185	205	189	181	164
Magnesia:						
First extraction	2,196	1,784	1,714	2,021	1,199	lost
Second extraction	989	351	1,153	554	1,008	601
Third extraction	728	543	1,012	722	388	406
Fourth extraction	952	355	786	558	202	243
Fifth extraction	627	446	lost	553	297	254
Sixth extraction	1,029	525	721	742	289	264

Effect of Concentration of Acid on Solubility.—Table 21 shows the effect of different concentrations of nitric acid upon three soils. Other results are given in Table 21. Increasing the concentration of the acid increases the amount dissolved, but not in proportion to the strength of the acid. For instance, making the acid two and one-half times stronger (N/5 to N/2) increased the average amount dissolved about 20 per cent. Increasing it from N/2 to 2N, or four times, made an increase of about 25 per cent in the dissolved material. This is further evidence of the difference in the solubility of the compounds of the same element in the soil.

Relation of Citric to Nitric Acid.—In order to ascertain what differences exist between citric and nitric acid, the same soils were treated with 1 per cent citric acid and N/5 nitric acid (five hours at 40° C.) and the solution subjected to analysis. There were selected for this experiment soils which showed differences between

the quantities of phosphoric acid dissolved by the two solvents. (See Table 22.)

TABLE 21.

Effect of Concentration of Acid on Solubility of Soil Constituent.

Laboratory Number.		Nitric Acid		
		N/5	N/2	2N
125	Silica (dissolved) per cent	0.21	0.33	0.49
326	Silica (dissolved)	0.44	0.52	0.27
336	Silica (dissolved)	0.18	0.24	0.37
	Average	0.28	0.36	0.30
	Per cent	100	129	135
125	Oxides of iron and alumina	0.11	0.18	0.28
326	Oxides of iron and alumina	1.39	1.43	1.76
336	Oxides of iron and alumina	0.58	0.81	1.17
	Average	0.69	0.81	1.07
	Per cent	100	117	154
125	Lime	.009	.010	.008
326	Lime	1.40	1.37	1.65
336	Lime	0.34	0.41	0.43
	Average	0.58	0.63	0.70
	Per cent	100	109	121
125	Magnesia	0.018	0.022	0.039
326	Magnesia	0.06	.085	.092
336	Magnesia	.041	.058	.090
	Average	0.040	.055	.071
	Per cent	100	137	177
125	Phosphoric Acid per million	9	19	26
326	Phosphoric Acid per million	420	500	550
336	Phosphoric Acid per million	9	10	14

The solvent action of citric acid is lower than N/5 nitric acid on practically all the soils. The differences are apparent both for oxides of iron and alumina, and for magnesia, and all the differences are in the same direction. That is to say, in none of these soils does the citric acid dissolve more than the nitric acid.

TABLE 22.

Relative Solvent Power of Citric and Nitric Acids.

Laboratory Number.		Oxides of iron and alumina		Lime		Magnesia		P_2O_5 per million	
		1% Citric	N/5 HNO_3	1% Citric	N/5 HNO_3	1% Citric	N/5 HNO_3	Citric	N/5 HNO_3
336		0.14	0.58	0.10	.34	.01	.045	.....	.....
176		.03	.04	.02	.03	.01	.03	9	8
178		.09	.31	.22	.26	.02	.03	51	30
180		.04	.10	.06	.08	.02	.03	12	12
103		.14	.46	.11	.26	.02	.016	10	11
110		.09	.43	1.90	.436	0.02	.016	74	61
125		.07	.12	.01	.01	.01	.07	12	9
	Average per cent...	0.086	0.29	0.35	0.76	.016	.034	.....	.....

SIGNIFICANCE OF THE PHOSPHORIC ACID DISSOLVED BY DILUTE ACIDS.

In the preceding pages the fact has been established that the phosphoric acid extracted from the soil by N/5 nitric acid (or some other weak solvent) does not represent the phosphoric acid which goes into solution. What it represents is the condition of equilibrium between the phosphoric acid dissolved, and the fixing power of the soil for phosphoric acid. Further, the phosphoric acid dissolved is not alone that upon the surface of the soil grains, but that within such soil particles as are soluble or partly soluble in the solvent. Any interpretation of a soil analysis which leaves out of consideration these three factors, is liable to be wrong.

Before making an interpretation of the meaning of the phosphoric acid dissolved from a soil by a weak solvent, it is necessary to have the following information:

(1) The quantity of extracted phosphoric acid.
(2) The acid consumed.
(3) The fixing power of the soil.

Under exceptional conditions it may be necessary to know, in addition:

(4) The phosphoric acid extracted by successive extractions.
(5) The complete composition of the soil extract.
(6) The fixation from the solution of the solvent.

Significance of the Dissolved Phosphoric Acid.—When 10 or less parts per million of phosphoric acid is present, associated with a fixing power of less than 50 per cent, and with acid consumed less than 90 per cent, it indicates that practically none of the phosphoric acid of the soil is present as apatite, calcium phosphate, or similar compounds, but must be present as basic phosphates or basic aluminium phosphate.

When 10 or less parts phosphoric acid are present and the soil has a high fixing power for phosphoric acid (75 per cent or more), calcium phosphates may or may not be present. That is to say, our method can not in this case distinguish between phosphoric acid which goes into solution from calcium phosphate and is then removed by fixation, and that which comes from the basic phosphates of the soil. The origin of the soil will throw some light upon the matter. If the soil is geologically old, the phosphoric acid has probably all been converted into basic phosphates. If the soil has been recently formed from rocks containing apatite and other phosphatic minerals, it is possible that calcium phosphate may still be present. In the majority of soils having a high fixing power and a low content of phosphoric acid, provided that they have not become fertilized, the phosphoric acid is probably present as basic iron and aluminium phosphates.

A soil of high fixing power such as above mentioned would yield up the same quantity of phosphoric acid to the solvent, whether fertilized or not fertilized, unless a very heavy application of phosphoric acid has been made. One thousand pounds of 16 per cent acid phosphate would represent an application of 80 parts per million of phosphoric acid, and this heavy application would not increase very much the phosphoric acid removed from soils of very high fixing power.

A soil containing 100 parts per million of phosphoric acid, with a low acid consumed, and with a fixing power of less than 50, probably contains a corresponding amount of calcium phosphate accessible to the roots of plants.

A soil containing 100 parts per million of phosphoric acid, with an acid consumed of 20 per cent, may or may not expose much phosphoric acid to the roots of plants. It is impossible to say how much of it is protected by the calcareous material.

It is impossible to distinguish phosphoric acid in its several different forms. For example, suppose plots were fertilized with Thomas phosphate, phosphate rock, acid phosphate, and apatite. We could not expect to find a relation between the phosphoric acid dissolved from these plots and the crop production. All these materials would give up their phosphoric acid equally well to the solvent used.

RELATION OF POT EXPERIMENTS TO THE ACTIVE PHOSPHORIC ACID.

For about four years we have been making pot experiments with representative Texas soils from different parts of the State. These experiments were carried on under varied conditions. With some of them the conditions were very favorable, while with other groups the conditions were not so suitable. The results are, therefore, not comparable one with another. We can, however, compare the crops produced on the pots receiving phosphoric acid with those without phosphoric acid.

From the work presented on the previous pages, it appears that the phosphoric acid dissolved by fifth-normal nitric acid from a natural soil, in excess of 9 parts per million, as a rule, comes from the phosphates of lime. There may be soils which contain easily-soluble non-basic phosphates of iron and aluminum, but we are inclined to believe that such soils are exceptional.

It does not follow that soils containing the same quantity of phosphates of lime should react in the same manner towards phosphatic fertilizers. The phosphates may be different in value in different soils.

The phosphates which are dissolved by a solvent may be on the

outside of soil particles, and exposed to plant roots, or within the soil particles, as already pointed out.

The phosphoric acid dissolved from a soil in excess of 8 parts per million is, in most cases, present as phosphate of lime. But we must make a distinction between the phosphate which goes into solution and that which is removed in the extract. A portion of the dissolved phosphoric acid is withdrawn from solution by the soil.

Reducing it to its lowest terms, the analysis of a soil with N/5 nitric acid amounts to this:

Knowing the quantity of phosphoric acid extracted by the solvent, and the absorptive power of the soil for phosphoric acid, we must estimate how much phosphate of lime is present in the soil. Then, knowing the amount of acid consumed, we must judge to what extent this phosphate is distributed within the mass of the dissolved material, and to what extent it is exposed to the roots of the plants. Having estimated the amount of exposed phosphate of lime, we have next to inquire how much of it is necessary to make a soil fertile? What conditions affect the rate and the quantity of phosphoric acid which these phosphates give up? Then we have to consider the probable value of the basic ferric and aluminium phosphates, which are present, and whether or not organic phosphates may not be in the soil. Having considered all these questions we shall be in a position to interpret the analysis of a soil with N/5 nitric acid.

CONDITIONS WHICH AFFECT PRODUCTION IN POTS.

In pot experiments, the attempt is made to keep all conditions constant except the one to be tested, maintaining the others as favorable as possible. It is, however, impossible to maintain only one variable. The main variable may be predominant, but there are others to be considered. Suppose, for example, we are studying the effect of acid phosphate on the soil, as is the case with much of the work here presented. We apply a complete fertilizer containing phosphoric acid, potash, and nitrogen, and compare its effect with a sample to which potash and nitrogen only are added. The variable is thus phosphoric acid. But in addition the phosphoric acid may undoubtedly affect the bacterial life in the soil, and this effect may conceivably be either favorable or unfavorable to the development of the plant. The effect upon the bacterial life may vary in different soils. The phosphatic fertilizer may also have some effect upon the reaction of the soil, according to the kind of material used, and this may vary from soil to soil. It is quite possible that these secondary reactions may on some soils have greater effect than the primary one, namely, the presence or absence of the phosphoric acid. It is obvious, however, that some controlling condi-

tion must limit the size of the crop in pot experiments, either the season and climatic conditions, the soil, or soil conditions. Suppose the conditions are so favorable that the phosphoric acid in the soil and fertilizer, together, becomes the controlling condition. It is obvious that the phosphoric acid of the soil can not alone force as large a production as the fertilized soil, so that the soil must appear deficient. The soil may be an excellent one, and able to yield good crops without fertilizers, but if in our pot experiments other conditions are so favorable that the total and largest amount of phosphoric acid becomes the limiting condition, the soil must appear as deficient no matter how good it is. The crop from the unfertilized soil will be large, but that from the fertilized one will be larger. This is, of course, an extreme case. Seasonal conditions and the seed will often limit the crop. Yet it is possible in pot experiments to demand of the soil in the pot more than very fertile soils can accomplish in the field. We shall come back to this subject later.

The conditions under which pot experiments are made are undoubtedly, in some respects, more favorable to the soil than field conditions. Some of the conditions may also be less favorable. In our work, the soil is well pulverized, and thus in a good mechanical condition. It is usually air-dry, and it has been shown that air-dried soils are perhaps more productive than the same soil not dried. The soil is subventilated, and this is a distinct advantage, especially for heavy clayey soils. The temperature in the pots is probably higher than the temperature of the soil in the field. The application of results of pot experiments to field conditions must be made a subject of study.

METHOD OF WORK.

These pot experiments were not all conducted in exactly the same manner, but the general procedure is as follows:

Washed gravel was added in sufficient amounts to an 8-inch Wagner pot to make the total weight 2 kilograms. Five kilograms of soil was then added. The soil had been previously pulverized in a wooden box with a wooden mallet until it would pass a 3 mm. sieve, gravel being removed.

The addition of fertilizer consists of $2\frac{1}{2}$ grams of acid phosphate, 1 gram nitrate of soda, and 1 gram sulphate of potash. In later experiments 1 gram of ammonium nitrate was used in place of nitrate of soda. If the size of the crop appeared to render it necessary, more nitrate of soda or sulphate of potash was added to the pot. They were added in solution, 10 c.c. equals 1 gram, but if added after planting, the solution was diluted with about 200 c.c. of water.

The seed were weighed out so that each pot received the same amount of seed within 0.1 of a gram. Water was added to one-half the saturation capacity of the soil. If this quantity was found to be too great, it was afterwards reduced, but this was the case in only a few instances. The pots were weighed, placed on scales three times a week, and water added to restore the loss in weight. If the plants needed water between these weighings, such quantity was added as appeared necessary. The object of the weighing was to maintain as closely as possible a constant amount of water in the soil.

A few of these experiments were conducted in a greenhouse belonging to the Horticultural Department, and a number were made on trucks covered with wire mosquito netting. The trucks were pulled into the house when a storm threatened. Later experiments were made in houses covered with canvas. These houses appear to be very well suited to pot experiments under our climatic conditions. They are much better for this purpose than glass houses for the reason that the circulation of the air is considerably better and the house does not become so heated as a glass house would. Some of these experiments were carried on in houses with glass roof and canvas sides. This also appears to be a good form of house for our climatic conditions. A house with glass top and wire mosquito netting sides is also being used. In some respects this is better than the canvas house, but in other respects it is not. The canvas houses are somewhat cooler. The open house is hotter, but the plants are of heavier growth than in the canvas house.

RELATION OF DEFICIENCIES OF CROPS TO ACTIVE PHOSPHORIC ACID.

Results of the pot experiments so far as phosphoric acid is concerned are presented in Table 23. The soils are divided into a number of groups, according to the quantity of active phosphoric acid contained in them. The number of the group represents the maximum quantity of phosphoric acid in the soil in milligrams per 100 grams. That is to say, Group 1 comprises such soils as contain 10 or less than 10 parts per million of phosphoric acid, or 1 or less than 1 milligram phosphoric acid in 100 grams. In Group 2 are soils containing 10.1 to 20 parts per million. Group 3 contains 20.1 to 30 parts per million and so on. Some of the groups are not represented in our table and some are combined, on account of the small number of soils contained in them. Groups Nos. 1 and 2 would have been larger but for the fact that pot experiments on soils containing less than 20 parts per million of phosphoric acid were discontinued in the latter part of our work, excepting when the soil appeared to present something unusual.

TABLE 23—Group 1

Laboratory Number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power. Per cent.	Pot experiment. NK Grams.	Pot experiment. PNK Grams.	Crop.	Period of growth.
176	Norfolk fine sandy loam	D	7.5	0	14.2	14.4	19.5	Cow peas.	5-31— 8- 4
306	Susquehanna fine sandy loam	DD	9	2	28.9	1.9	10.9	Corn.	4-18— 6- 8
		DD	.....	.....	.....	2.7	8.4	Cow peas.	?
		DD	.....	.....	.....	1.9	8.0	Oats.	?
310	Orangeburg fine sandy loam	DD	3	1.3	44.1	2.9	6.1	Corn.	4-18— 6- 8
		DD	.....	.....	.....	1.6	4.0	Cow peas.	?
		DD	.....	.....	.....	1.9	5.0	Oats.	?
		DD	.....	.....	.....	7.7	37.0	Corn.	6-11— 7-31
316	Norfolk fine sandy loam	DD	6	2	10.1	1.9	12.7	Corn.	4-18— 6- 8
		DD	.....	.....	.....	2.7	7.7	Cow peas.	?
		DD	.....	.....	.....	1.9	7.0	Oats.	?
324	Houston black clay	DD	9.3	100	71.4	6.4	16.1	Corn.	7-19— 9-10
		S	.....	.....	.....	6.0	2.5	Oats.	7-19— 9-20
336	Susquehanna fine sandy loam	DD	7	15	86.1	2.1	20.1	Corn.	7-19— 9-10
342	Orangeburg fine sand	S	8.0	2.0	26.9	1.9	2.0	Corn.	7-19— 9-10
		D	.....	.....	.....	6.5	10.5	Oats.	7-19— 9-10
344	Orangeburg fine sandy loam	DD	4.9	3.3	75.5	1.0	4.0	Oats.	?
819	Norfolk fine sandy loam	DD	6	0.8	12.3	1.7	18.0	Corn.	5-11— 8- 5
		DD	.....	.....	.....	0.7	1.9	Wheat.	2- 6— 5- 8
820	Susquehanna fine sandy loam	DD	9	2.9	39	1	12.5	Corn.	4- 6— 5-27
821	Orangeburg fine sand	DD	5	2.4	44.8	2.3	10.8	Corn.	4- 6— 7- 6
		DD	.....	.....	.....	0.4	5.0	Corn.	5-12— 8- 2
		D	.....	.....	.....	3.9	7.2	Corn.	9-11—11-12
		S	.....	.....	.....	2.0	1.5	Mustard.	10-16—12-18
822	Lufkin fine sandy loam	DD	7	0	78.2	2.5	20.6	Corn.	4- 6— 5-11
828	Norfolk fine sand	DD	8	0.3	3.8	4.5	19.2	Corn.	4-17— 6-11
850	Susquehanna sandy loam	DD	6	4.7	31.2	1.2	18.0	Corn.	5- 1— 6-19
1138	Susquehanna fine sandy loam	DD	7.5	8.2	97.6	4	20.2	Corn.	4-30— 6-23

Group 2.

Laboratory number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power. Per cent.	Pot experiment. NK Grams.	Pot experiment. PNK Grams.	Crop.	Period of growth.
97	Heavy black rice soil	DD	13	15.3	93	3.1	6.9	Cotton	7-20— 9- 8
131	Orangeburg fine sand	DD	14	2.4	21.1	3.1	14.1	Corn	7-11— 7-20
141	Rice soil under cultivation 3 years	D	18	.....	81.5	2.4	3.6	Cotton	7- 8— 9- 8
180	Orangeburg fine sandy loam	D	12	0	22.5	15.7	21.8	Cow peas	5-31— 8- 4
314	Norfolk fine sand	DD	18	1.0	16.0	1.6	10.7	Corn	4- 8— 6- 8
		D	.....	.....	.....	8.6	9.4	Cow peas	?
		S	.....	.....	.....	8.0	4.5	Oats	?
332	Houston clay	D	12	100	84.8	8.0	14.5	Oats	?
334	Houston loam	DD	12	8.0	62.5	8.5	30.1	Corn*	7-19— 9-10
		D	.....	.....	.....	4.5	8.5	Oats	7-19— 9-10
340	Susquehanna fine sandy loam	DD	13	24	28	3.0	12.0	Corn	5-11— 8- 5
		DD	.....	.....	.....	2.0	4.0	Oats	7-19— 9-10
		DD	.....	.....	.....	0.3	1.3	Grass	2- 6— 5- 8
		S	.....	.....	.....	3.9	0.1	Mustard	10-16—12-18
816	Laredo fine sand	DD	12	2.4	56.4	3.9	16.2	Corn	4- 6— 6-11
		S	.....	.....	.....	3.2	3.4	Corn	9-11—11- 2
		DD	.....	.....	.....	2.8	6.2	Grass	1-28— 6- 4
		DD	.....	.....	.....	5.0	10.8	Mustard	10-22—12-18
817	Lufkin fine sandy loam	DD	11	3.5	56.8	12.5	30.0	Corn	4- 6— 7- 6
		DD	.....	.....	.....	1.2	3.7	Corn	9-11—11- 2
		D	.....	.....	.....	2.0	3.1	Grass	1-28— 6- 4
834	Orangeburg fine sandy loam	DD	11	6.6	59.5	3.4	24.6	Corn	4-17— 6-14
843	Wabash heavy clay	DD	14	11.5	72.1	5.6	16.1	Corn	5-11— 8- 5
		.....	.....	.....	.....	1.4	3.7	Wheat	2- 6— 5- 8
		.....	.....	.....	.....	31.4	46.1	Corn	5- 1— 6-19
		S	.....	.....	.....	2.4	2.6	Mustard	10-16—12-18
859	Norfolk fine sand	DD	19.0	0.5	2.4	6.8	29.8	Corn	5- 3— 7- 6
913	Susquehanna fine sandy loam	DD	18.7	1.2	22.4	3.1	6.4	Corn	9- 7—11-12
937	Orangeburg fine sandy loam	D	13.5	25.0	9.6	5.2	8.4	Corn	9-11—11-21
1120	Susquehanna fine sand	DD	13.7	1.9	28	1.0	13	Corn	4-30— 6-23
		S	.....	.....	.....	4.8	5.1	Mustard	10-22—12-18
1124	Winfield fine sandy loam	DD	11.8	4	75.4	5.0	21.0	Corn	4-30— 6-23
		D	.....	.....	.....	3.7	4.6	Mustard	10-22—12-18
1126	Winfield fine sand S. S.	DD	12	2	78	3.5	26.2	Corn	4-30— 6-23
1136	Norfolk fine sandy loam S. S.	DD	10	4	52	1.0	23.0	Corn	4-30— 6-23

1140	Lufkin fine sandy loam S. S.	DD	11.9	4.2	50.8	2.9	45.5	Corn.....	4-30— 6-23
1583	Houston gravelly clay S. S.	D	14	47.5	87.5	5.2	7.2	Mustard...	9-15—11- 3
1585	Willis sand S. S.	D	18	2	26.6	7.3	9.7	Mustard...	9-15—11- 3
1586	San Jacinto clay	D	14	3.0	33.2	6.6	10.2	Mustard...	9-15—11- 3
1587	San Jacinto clay S. S.	DD	11	5.4	85.1	4.0	9.3	Mustard...	9-15—11- 3
1588	Lufkin sandy loam	D	15	2.0	12.3	6.0	8.7	Mustard...	9-15—11- 3
1589	Lufkin sandy loam S. S.	SS	11	5.1	63.6	4.6	5.1	Mustard...	9-15—11- 3
1590	Deep S. S. to 1588	DD	11	11	84.1	1.7	4.2	Mustard...	9-15—11- 3
1591	Lufkin sand	D	16.2	2.0	4.3	4.9	7.5	Mustard...	9-15—11- 3
1130	Lufkin silt loam	DD	15.6	2.0	72.5	2	29	Corn.....	4-30— 6-23
	Average (corn)	.....	.....	10.6	51.1	5.4	20.5		

*Not dry, second weighing (moulded) 13.2 gm.

Group 3.

Laboratory Number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power. Per cent.	Pot experiment. NK Grams.	Pot experiment. PNK Grams.	Crop.	Period of growth.
76	Norfolk fine sandy loam	D	22	0.9	25.4	4.7	9.2	Corn	6–11— 7–20
		DD	23	100	77.7	2.9	6.1	Cotton	7–20 — 9– 8
108	Yazoo sandy loam	D	29	40	8.0	15.3	18.2	Cotton	7– 8— 9–10
135	Norfolk sand	D	29			2.5	4.9	Cotton	7–25— 9–18
137	Rice soil	D	23.5	4	10.4	17.1	22.0	Cow peas	5–31— 8– 4
174	Norfolk fine sand	D	29	10	55.8	20.9	24.3	Cow peas	5–31— 8– 4
178	Orangeburg clay	D	22.8	11.8	81.7	19.5	31.4	Corn	4–17— 6–19
829	Houston loam	DD				1.2	5.0	Corn	9–11—11–12
		D				4.6	7.2	Grass	1–28— 6– 3
832	Orangeburg clay	DD	24.3	6.1	87.1	1.8	36.2	Corn	9–11—11–12
860	Orangeburg fine sand	DD	21.32		8.0	11.8	36.1	Corn	5– 3— 7– 6
		D				1.9	2.5	Corn	9–11—11–12
893	Lufkin clay	D	20.2	2.0	69.9	4.6	5.5	Corn	9– 7—11–12
		DD				2.2	4.6	Grass	1–28— 6– 3
		S				1.6	1.3	Mustard	10–16—12–18
911	Norfolk fine sand	D	21.2	1.9	8.3	1.7	2.5	Grass	1–28— 6– 3
941	Houston loam	DD	29.7	4.8	82.7	20.4	13.2	Corn	9–11—11–12
		DD				3.2	7.0	Grass	1–28— 6– 4
		D				5.3	9.7	Mustard	10–16—12–18
1119	Susquehanna fine sand	DD	25.5	3.0	19.6	13.5	34.6	Corn	4–27— 6–18
		D				4.8	6.3	Mustard	10–22—12–18
1123	Winfield fine sandy loam	D	24	5.2	50.0	15.2	25.8	Corn	4–27— 6–18
1207	Nueces fine sandy loam S. S	DD	26	9	91.8	2	26.0	Corn	10–22—12–18
		D				2.4	6.4	Mustard	10–22—12–18
1578	San Antonio clay loam S. S	S	24	99	67.7	9.0	9.7	Mustard	9–15—11– 3
1592	Lufkin sand S. S	DD	23	20	2.9	3.4	6.9	Mustard	9–15—11– 3
1594	Houston black clay S. S	D	29	91	74.6	7.0	11.3	Mustard	9–15—11– 3
	Average			24.2	48.3	7.1	20.4		

Group 4.

Laboratory Number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power. Per cent.	Pot experiment. NK Grams.	Pot experiment. PNK Grams.	Crop.	Period of growth.
172	Norfolk sand	DD	35	1.9	14.4	3.0	9.7	Corn	5-12— 8- 2
		S				10.5	10.2	Cow peas	?
		DD				3.0	6.0	Oats	?
1328	Blanco loam	DD	36	100	67.8	7.1	17.9	Corn	7-19— 9-10
		D				7.0	9.0	Oats	7-19— 9-10
330	Crawford stony clay	D	31	100	86.7	15.0	19.8	Corn	7-19— 9-10
		S				9.1	6.9	Oats	7-19— 9-10
910	Houston black clay	D	36.3	17.2	72.6	3.9	6.5	Corn	9- 7—11-12
		S				6.2	5.4	Grass	1-28— 6- 3
		S				7.9	8.2	Mustard	10-16—12-18
914	Lufkin fine sandy loam	D	38		28.9	6.6	10.9	Corn	9- 7—11-12
		DD				1.5	3.8	Grass	1-28— 6- 3
1577	San Antonio clay loam	D	39	100	57.7	10.2	11.9	Mustard	9-15—11- 5
1582	Houston gravelly clay	D	31	35.4	71.7	6.4	9.9	Mustard	9-15—11- 3
	Average (corn)			50.7	57.1	7.1	12.6		

Groups 5 and 6.

Laboratory Number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power. Per cent.	Pot experiment.		Crop.	Period of growth.
						NK Grams.	PNK Grams.		
127	Houston black clay	D	41	20.8	51.3	6.9	12.0	Corn	4-18— 6- 8
		D				9.2	13.2	Cow peas	?
128	Norfolk silt loam	D	45	8.7	53.5	3.1	4.9	Cotton	7-15— 8-17
830	Laredo gravelly loam	S	41	7.3	48.3	4.5	5.0	Corn	4-17— 7- 6
133	Sander's loam	DD	53	6.7	43.3	2.5	11.9	Corn	4-18— 6- 8
		D				7.0	10.2	Oats	?
851	Wilson clay loam	D	52.5	19.5	24	16.8	23.4	Corn	5- 1— 6-19
		D				2.9	4.5	Grass	5-27— 6- 3
935	Lufkin clay	D	53.3	3.0	57.2	5.5	4.5	Corn	9-11—11-12
		DD				0.3	2.9	Grass	1-28— 6- 4
940	Wilson loam	S	54.3	54.5	67.9	7.3	6.7	Corn	9-11—11-12
		S				7.0	5.0	Grass	2- 6— 5- 8
		S				9.2	10.1	Mustard	10-22—12-18
134	San Antonio clay loam	D	49.4	100	74.2	6.6	9.5	Corn	4-18— 6- 8
		D				5.0	8.3	Oats	?
	Average			27.6	52.5	7.1	10.4		

Groups 7 and 8.

Laboratory Number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power Per cent.	Pot experiment. NK Grams.	Pot experiment. PNK Grams.	Crop.	Period of growth.
129	Lufkin clay	DD	60.5	6.1	52.9	0.9	3.3	Cotton	7- 8— 8-17
211	Probably Norfolk sand or fine sand	D	61	.....	.....	2.9	4.9	Corn	4-18— 6- 8
		D	.....	.....	.....	5.0	7.5	Oats	?
818	Wabash fine sandy loam	D	67	3.9	31.9	34.2	43.1	Corn	9-11—11-12
1134	Norfolk fine sand S. S.	D	68.7	2.8	5.6	18.0	29.4	Corn	4-30— 6-23
		D	.....	.....	.....	5.2	6.6	Mustard	10-22—12-18
1205	Houston loam S. S.	D	60	39	39.8	10.0	16.0	Corn	3- 7— 6-23
		D	.....	.....	.....	6.3	10.2	Mustard	10-22—12-18
1597	Yazoo sandy loam	D	61	100	42.3	8.2	10.4	Mustard	9-15—11- 3
1598	Yazoo sandy loam S. S.	D	63	99	46.7	6.1	9.0	Mustard	9-15—11- 3
833	Laredo fine sandy loam	D	75	7.5	50.6	17.0	29.0	Corn	4-17— 6-11
		S	.....	.....	.....	5.9	2.2	Corn	9-11—11-12
		S	.....	.....	.....	5.7	5.9	Grass	1-28— 6- 4
932	Miller silt loam	D	70.7	99.0	67.2	5.4	6.2	Corn	9-11—11-12
		DD	.....	.....	.....	2.3	6.7	Grass	1-28— 6- 4
939	Houston black clay	D	76.3	100	74.6	4.3	6.5	Corn	9-11—11-12
		S	.....	.....	.....	13.1	13.2	Mustard	10-11—12-18
982	Cameron clay S. S.	D	72	99	82	26.1	50.9	Corn	5- 7— 6-23
		S	.....	.....	.....	8.1	8.1	Mustard	10-22—12-18
1581	Houston black clay loam S. S.	D	71	26.3	45.3	7.1	9.9	Mustard	9-15—11- 3
1593	Houston black clay	D	74	32.3	51.9	10.5	12.0	Mustard	9-15—11- 3
1596	Austin clay S. S.	D	74	2.0	12.6	3.5	4.0	Mustard	9-15—11- 3
1599	Houston black clay	D	77	50	70.6	6.1	13.0	Mustard	9-15—11- 3
	Average (corn)	.....	.....	47.6	48.1	13.8	20.9		

Groups 9 and 10 and 11 and 16.

Laboratory Number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power. Per cent.	Pot experiment. NK Grams.	Pot experiment. PNK Grams.	Crop.	Period of growth.
	Table A—Group 9:								
933	Bastrop clay	S	87.7	1.0	77.3	5.0	3.1	Corn	9–11—11–12
		DD	.....	.....	.....	0.4	5.5	Grass	1–28— 6– 3
		D	.....	.....	.....	12.3	15.9	Mustard	10–16—12–18
1579	Norfolk silt loam	D	87	40.4	62.6	6.5	10.2	Mustard	9–15—11– 3
1580	Houston black clay loam	D	84	68.7	56.6	8.0	11.0	Mustard	9–15—11– 3
1600	Houston black clay S. S.	S	69	25.3	75.4	10.1	11.1	Mustard	9–15—11– 3
	Table A—Group 10:								
318	Lufkin fine sand	D	98	2	9.2	3.4	4.9	Corn	5– 7— 6–23
		S	.....	.....	.....	3.2	2.6	Cow peas	?
		D	.....	.....	.....	6.0	6.9	Oats	?
1122	Hagensport loam S. S.	DD	99	1	97.6	2.0	24.3	Corn	4–30— 6–23
1133	Norfolk fine sand	S	92.5	3.3	12.0	25.3	15.9	Corn	4–27— 6–18
		S	.....	.....	.....	5.0	5.0	Mustard	10–22—12–18
338	Yazoo clay	D	96.9	100	63.3	7.1	12.0	Corn	7–19— 9–10
		DD	.....	.....	.....	2.0	5.9	Oats	7–19— 9–10
	Average Groups 9 and 10	.....	.....	33.9	56.8	8.6	12.0	.....	.....
	Table A— Group 11:								
1203	Houston clay S. S.	DD	103	43	61.9	6.0	29.7	Corn	.....
		D	.....	.....	.....	5.4	6.8	Mustard	10–22—12–18
	Table A—Group 13:								
845	Wabash silt loam	S	120.2	10	62.1	21.8	29.2	Corn	5– 1— 6–19
		S	.....	.....	.....	11.5	8.0	Corn	9– 4—11–12
		D	.....	.....	.....	7.5	9.9	Grass	1–28— 6– 4
1206	Nueces fine sandy loam	S	125	4	7.6	16.2	17.5	Corn	4–30— 6–23
	Table A—Group 15:								
182	Yazoo clay	D	142	55	96.9	2.5	3.6	Corn	4–18— 6– 8
		S	.....	.....	.....	4.0	4.4	Cow peas	?
		D	.....	.....	.....	.8	1.1	Grass	3–27— 6– 3
		S	.....	.....	.....	20.2	18.2	Mustard	10–16—12–18

	Table A—Group 16:									
1131	Wabash clay	D	154	30.6	89.6	36.0	47.8	Corn	4-30— 6-23
		S	.....	.....	.....	12.1	13.2	Mustard	10-22—12-18
1204	Houston loam	S	157	21	37.6	14.9	14.4	Corn	4-30— 6-23
		S	.....	.....	.....	7.0	7.7	Mustard	10-22—12-18
1595	Austin clay	D	152	4.0	22.2	6.9	9.9	Mustard	9-15—11- 3
1202	Houston clay	D	192	47	70.8	23	36.3	Corn	4-30— 6-23
		S	.....	.....	.....	7.2	7.3	Mustard	10-22—12-18
	Average (corn) Groups 11 to 19	.....	.....	26.8	56.1	14.4	23.3	.....	.....

Groups 32 to 60.

Laboratory Number.		Deficiency.	Active phosphoric acid. Per million.	Acid consumed. Per cent.	Fixing power. Per cent.	Pot experiment. NK Grams	Pot experiment. PNK Grams.	Crop.	Period of growth.
	Table A—Group 32:								
934	Wabash clay	S	313.7	2.0	69.1	6.7	5.6	Corn	9–11—11–12
		D	.....	.....	.....	3.4	5.1	Grass	1–28— 6– 3
	Group 35:								
159	Fine red incoherent sand	S	350	42.0	16.9	4.0	4.4	Cotton	7–19— 9–10
	Table A—Group 39:								
827	Laredo silt loam	DD	392	84.2	47.5	4.3	15.5	Corn	4– 6— 6–11
		D	.....	.....	.....	2.1	3.5	Grass	1–28— 6– 4
		S	.....	.....	.....	6.9	7.5	Mustard	10–22—12–18
	Table A—Group 40:								
831	Laredo silty clay	D	393	53.4	72.4	53.3	60.0	Corn	4–17— 7– 6
		D	.....	.....	.....	1.1	1.9	Wheat	2– 6— 5– 8
		S	.....	.....	.....	48.9	46.9	Corn	5–11— 8– 5
	Group 42:								
912	Bastrop sandy loam	S	415.3	19.5	32.4	4.2	4.2	Corn	9– 7—11–12
		S	.....	.....	.....	56.2	47.7	Corn	5–12— 8– 2
938	Austin fine sandy loam	DD	419.7	99.5	29.3	2.3	8.8	Corn	9–11—11–12
		DD	.....	.....	.....	0.9	3.0	Wheat	2– 6— 5– 8
		S	.....	.....	.....	37.7	40.4	Corn	5–11— 8– 5
		D	.....	.....	.....	8.5	6.5	Mustard	10–16—12–18
	Average Groups 32 to 42	.....	.....	50.1	43.6	26.7	28.6		
	Table A—Group 60:								
976	Soil	D	752.5	28.7	51.1	4.9	7.6	Mustard	10–22—12–18

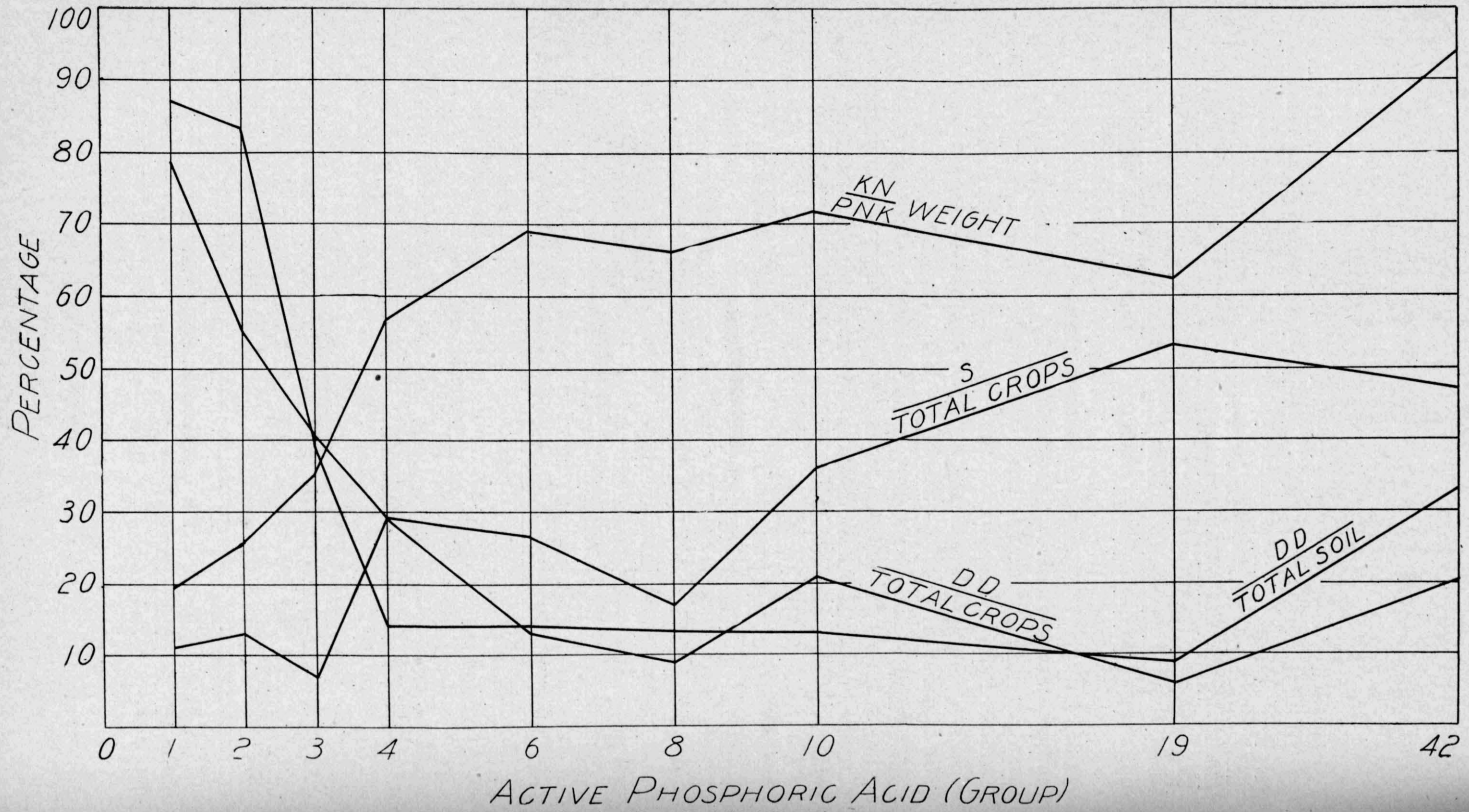


Fig. 3. The Relation of Active Phosphoric Acid to Crop Production and Soil Deficiencies.

In the following discussion we will consider all the crops which are shown in the table. There are some crops which should properly be excluded. These will be eliminated in connection with the discussion of the soil deficiencies, but not here. We must also remember, in this connection, that on some soils, four crops were grown and on others only one. But we are dealing here with individual crops, and not with the soil, which is left to a later section.

A crop is regarded as very deficient (DD) if it is only 50 per cent or less, of the completely fertilized crop. If it is less than 90 per cent it is considered deficient (D). If more than 90 per cent it is considered as not deficient (S).

A summary of the results is presented in Table 24.

Observing first the deficient crops, we find a large number in Groups 1 and 2, that is to say, in soils containing less than 20 parts per million of active phosphoric acid. In Group 3 there is an intermediate number. The number decreases more or less irregularly. These facts are brought out more clearly when we observe the percentage of very deficient crops. This percentage decreases regularly to Group 8, after which the results are somewhat irregular.

The number of deficient crops is, of course, related to the number very deficient, as well as to those containing sufficient phosphoric acid. It increases up to the eighth group, and the increase is regular if we exclude Group 4.

The number of sufficient crops is somewhat irregular, but, on a whole, increases as the quantity of phosphoric acid extracted from the soil increases. The highest percentages are in Groups 11-19.

These facts are also shown graphically in the curve of Fig. 3.

Relation to Weight of Crop.—The size of the crop depends upon climatic conditions and the period of growth allowed. The crops are grown under varied conditions, so that we cannot compare weights directly, yet it is somewhat striking to observe that while the crop with complete fertilizer varies, the average crop without phosphoric acid increases up to the eighth group. This, of course, may be to some extent accidental.

The crops produced with no phosphoric acid, divided by the crops produced with the complete fertilizer, expressed in percentages gives fairer means of comparison. This percentage increases regularly with the amount of active phosphoric acid in the soil through the entire series, with the exception of Groups 7-8 and 11-19. The difference between Groups 5-10 is very small, however, and the deficiency of Groups 7-8 is slight.

These results are also brought out in the curve (Fig. 3).

TABLE NO. 24—Summary of Pot Experiments.

	Groups.									
	1	2	3	4	5 and 6	7 and 8	9 and 10	11 to 19	32 to 42	60
Corn crop, average weight:										
KN grams	2.9	5.4	7.1	7.1	7.1	13.8	8.6	14.4	26.7	.....
KPN grams	14.8	20.5	40.4	12.6	10.4	20.9	12.0	23.3	28.6	.....
Crops averaged	16	20	14	5	7	9	5	8	8	.....
KN divided by KPN, in percentage	19.6	26.3	34.8	56.3	68.3	66.0	71.7	61.8	93.4	.....
All crops:										
Percentage, DD	78.6	55.5	40.7	28.5	13.3	8.7	21.4	5.9	20.0	.....
Percentage, D	10.7	31.1	51.9	42.8	60.0	73.9	42.8	41.1	33.3	.....
Percentage, S	10.7	13.3	7.4	28.5	26.6	17.4	35.7	52.9	46.6	.....

The average corn crop is clearly related to the quantity of active phosphoric acid in the soil. Soils containing less than 30 parts per million of active phosphoric acid are highly deficient in this form of plant food for corn. Soils containing up to 190 parts per million are deficient.

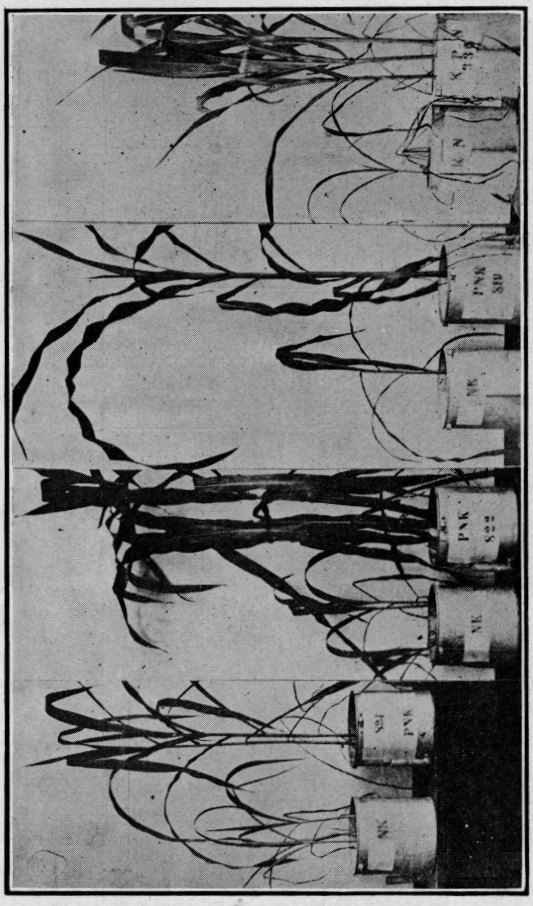


PLATE I.—Four soils of Group 1. Note the effect of phosphoric acid.

If the soils contain less than 30 parts per million, about 90 per cent of the crops are deficient; if between 30 and 80, from 70 to 83 per cent are deficient. Over 80 parts per million, the probability of a deficient crop decreases from 65 to 44, but the number of soils studied containing this quantity is too small to draw decisive conclusions.

DEFICIENCIES FOR SOILS.

The conclusions in the preceding sections were drawn from a consideration of all the crops grown in the experiments, without regard to the number grown upon the same soil, the size of the crop, or other conditions which should be considered. In this part of the Bulletin, we will form our judgment as to the needs of the soil,

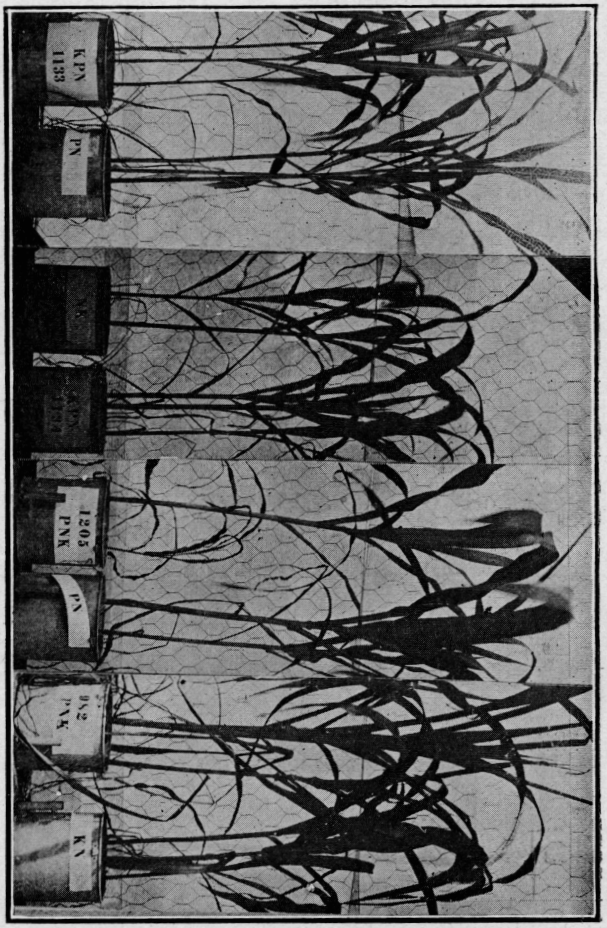


PLATE II.—Four soils of Groups 7—10.

from these experiments which are, in our opinion, entitled to the most weight. In some cases, the crops are so small as to be of doubtful value, while in others conditions were unfavorable to particular crops.

We place the most emphasis upon the results with the corn crop,

because this crop was, on the whole, the most satisfactory, and more crops of this kind were grown than of any other. Hence, when the results of the tests on the same soil are inconsistent, we attach more weight to the corn experiment than to the others. Some of the grass and wheat experiments are of little value. Seasonal conditions were, as a whole, not very favorable to good results while these crops were being grown. One series of corn crops was grown in the fall. The cool weather caused the corn to grow much more poorly than it does in the spring or fall.

The corn crop appears to be, on the whole, more sensitive to phosphoric acid than other crops. Where corn is *very* deficient, mustard is only deficient. A sufficient number of comparisons has not been made to warrant definite statements regarding the ability of various plants to assimilate phosphates, but this phase of the matter is being studied.

After due consideration, we have decided that the deficiencies of the soils are as shown in the following table. This table contains all the soils of Table 23, excepting one or two eleminated for the reasons given above. (See Table 25.)

TABLE NO. 25—Deficiencies of Soils.

	DD Very deficient.	D Deficient	S Not deficient
Group 1..	306, 310, 316, 324, 336, 344, 819, 820, 821, 822, 850, 1138.	173, 342	.....
Group 2..	97, 131, 314, 334, 340, 816, 817, 834, 843, 859, 1120, 1126, 1136, 1140, 1587, 1590, 1130, 913, 1124.	141, 180, 332	1589
Group 3..	108, 832, 860, 941, 1592, 1119, 1247	76, 135, 137, 174, 178, 829, 893, 911, 1123, 1594.	1578
Group 4..	172	328, 330, 1577, 1582	910
Group 5..	.....	127, 128	.....
Group 6..	133	134, 851	940, 935
Group 7..	129	211, 818, 1134, 1205, 1597, 1598	.....
Group 8..	833	932, 939, 982, 1581, 1593, 1596, 1599	.....
Group 9..	.....	933, 1579, 1580	1600
Group 10..	1122	318, 338	1133
Group 11..	1203	.....	.....
Group 13..	.....	.....	845, 1206
Group 15..	.....	.....	182
Group 16..	.....	1131, 1595	1204
Group 19..	.....	1202	.....
Group 32..	.....	.....	934
Group 35..	.....	.....	159
Group 39..	827	.....	.....
Group 40..	.....	.....	831
Group 42..	938	.....	912
Group 60..	.....	1976	.....

The results of this table are combined in Table 26, in which the number of soils decided to be very deficient, deficient, and not deficient, are given. Also the percentages are given of the total number in the group.

Of the 38 soils containing less than 20 parts per million of active phosphoric acid, we find 32 highly deficient, 5 deficient, and 1 suffi-

cient. The sufficient soil (No. 1589) had only one pot experiment made on it, and the results might very possibly have been different had more tests been made. We have already seen that the corn crop produced on soils of these groups with no phosphoric acid are only from 19 to 26 per cent, respectively, of the crop with phosphoric acid.

Soils containing 20 parts per million, or less, of active phosphoric acid are highly deficient in phosphoric acid.

Considering the table further, we find that the percentage of very deficient soils decreases rapidly from 87 per cent in the first group to 14 per cent in the fourth, after which it decreases slowly to the 11-17 group, after which there is a sudden increase. One soil, however, makes a great difference in the percentage in these groups.

TABLE NO. 26—Number and Percentage of Deficient Soils Grouped According to Content of Active Phosphoric Acid.

Group	Number of soils			Percentage of soils		
	DD	D	S	DD	D	S]
No. 1	13	2	0	87	13	0
No. 2	19	3	1	83	12	4
No. 3	7	10	1	39	55	6
No. 4	1	5	1	14	71	15
No. 5 and 6	1	4	2	14	57	28
No. 7 and 8	2	13	0	13	87	0
No. 9 and 10	1	5	2	13	63	24
No. 11-19	1	5	5	9	45	46
No. 32-42	2	0	4	33	0	66
Total	48	47	16			

The percentage of non-deficient soils increases with fair regularity throughout the table, though there are some breaks, notably in Group 7-8, all soils in which are deficient.

In Groups 3 to 10 are 55 soils, 12 of which are very deficient, 37 are deficient, and 6 appear to yield sufficient phosphoric acid. That is to say, about 11 per cent are not deficient. The average corn crop without phosphoric acid is from 34 to 71 per cent of that with phosphoric acid. We feel justified in drawing the following conclusion:

Soils containing from 30 to 100 parts per million of phosphoric acid soluble in N/5 nitric acid, are, as a rule, deficient in phosphoric acid, and the extent of their deficiency is related to the quantity of active phosphoric acid.

Group 11-19 contains only 11 soils. Nearly 50 per cent are not deficient. We draw the following conclusion, subject to modification when a larger number of soils are studied:

Soils containing from 100 to 200 parts per million of active

phosphoric acid are possibly deficient in phosphoric acid, the chances being even that they are or are not deficient. That is, of 10 soils in these groups, 5 will probably respond to phosphatic fertilizers.

Groups 32 to 42 contain only 6 soils. Such soils are likely *not* to be deficient in phosphoric acid, but the conclusion is likewise subject to modification from further study.

RELATION OF ACID CONSUMED AND FIXATION FOR PHOSPHORIC ACID.

The preceding discussion was based upon the phosphoric acid taken from the soil without regard to the fixing power or acid consumed. These values are given in Table 24, and their effect upon the results of the work will be discussed in this section.

A summary of the results is presented in Table 27. There is no general relation between the acid consumed, and the fixing power of the soil in the different groups, beyond the fact that average "acid consumed" in the first two groups is considerably lower than in all the others. That is to say, the soils of this group are, as a rule, non-calcareous, although calcareous soils are found within the group. The soils of the other groups, on an average, neutralize 25 per cent of the acid, and contain the equivalent of 2.5 per cent carbonate of lime. We consider such soils as calcareous. Non-calcareous soils are, however, found in all the groups.

Table 27 also shows percentage of acid consumed by the soils which do not conform to the general behavior of the soil as regards deficiency. For Group 1 and 2, the soils behave as highly deficient; so soils which are deficient, or not deficient, are considered as exceptional soils for these groups. In Groups 3-10 the soils are prevailingly deficient; so soils which are very deficient, or not deficient, are considered as exceptional. Soils very deficient are considered as exceptional in Groups 11-19 and 32-42.

We find in the table two exceptional soils in Group 1, having acid consumed of 0 and 2, respectively. In Group 2 there are 4 exceptional soils, with acid consumed of 0, 100, 5, and unknown.

The greater the acid consumed, the more soil material is brought into solution by the solvent, and the greater the probability that the dissolved material has exposed some of the protected soil phosphates. A high or very high acid consumed should, therefore, indicate the possibility that the soil may belong to a lower group than that in which it is placed.

In Groups 1-2, we find 3 of the exceptional soils with low acid consumed, and 1 with high. The former might be expected, the latter is indeed exceptional.

In Group 3-10, we find all the very deficient soils to be all soils of low acid consuming power, much lower than the average. Two of the not-deficient soils have an acid consuming power higher

than the average for the group, and 4 are lower. No general conclusions can be drawn from this data.

The results for fixing power are tabulated in Table 28. No relation can be seen between the group to which the soil belongs, and its fixing power.

The fixing power of a soil tends to place it in a higher group than the one in which it is found. The higher the fixing power, the greater the correction.

No relation can be traced between the percentages fixed by the exceptional soil, and relation of the exceptional soil to the others.

If we attempt to correct for the fixing power of the soil, we find, in some cases, no great change, only from one group to the next one. There are, however, soils on which a considerable change will be found, but on some of these the calcareous matter dissolved indicates that they really belong in a lower group. As we have already stated, we are unable to correct for acid consumed.

In Group 1, soils 336 and 1138 would probably be changed to Group 4 by correction for fixation, though reduced by acid consumed. Both these soils are very deficient, and evidently belong to Group 1. Since the phosphates dissolved in Group 1 do not probably come from calcium phosphates, we believe no correction should be made in this group.

In Group 2, soils 141, 332, 1583, 1587, 1590 would be perhaps raised to Groups 4-8 by correction for fixation. Three of these soils are deficient, and two are very deficient. Since a large part of the phosphates dissolved comes from phosphates of iron and aluminium, we are doubtful about making a correction.

In Group 3, soils 829, 832, 941, 1207 would be raised to Groups 4-10 by correction for fixation. Three of these soils are very deficient, and 1 is deficient. It would appear that the correction should not be made.

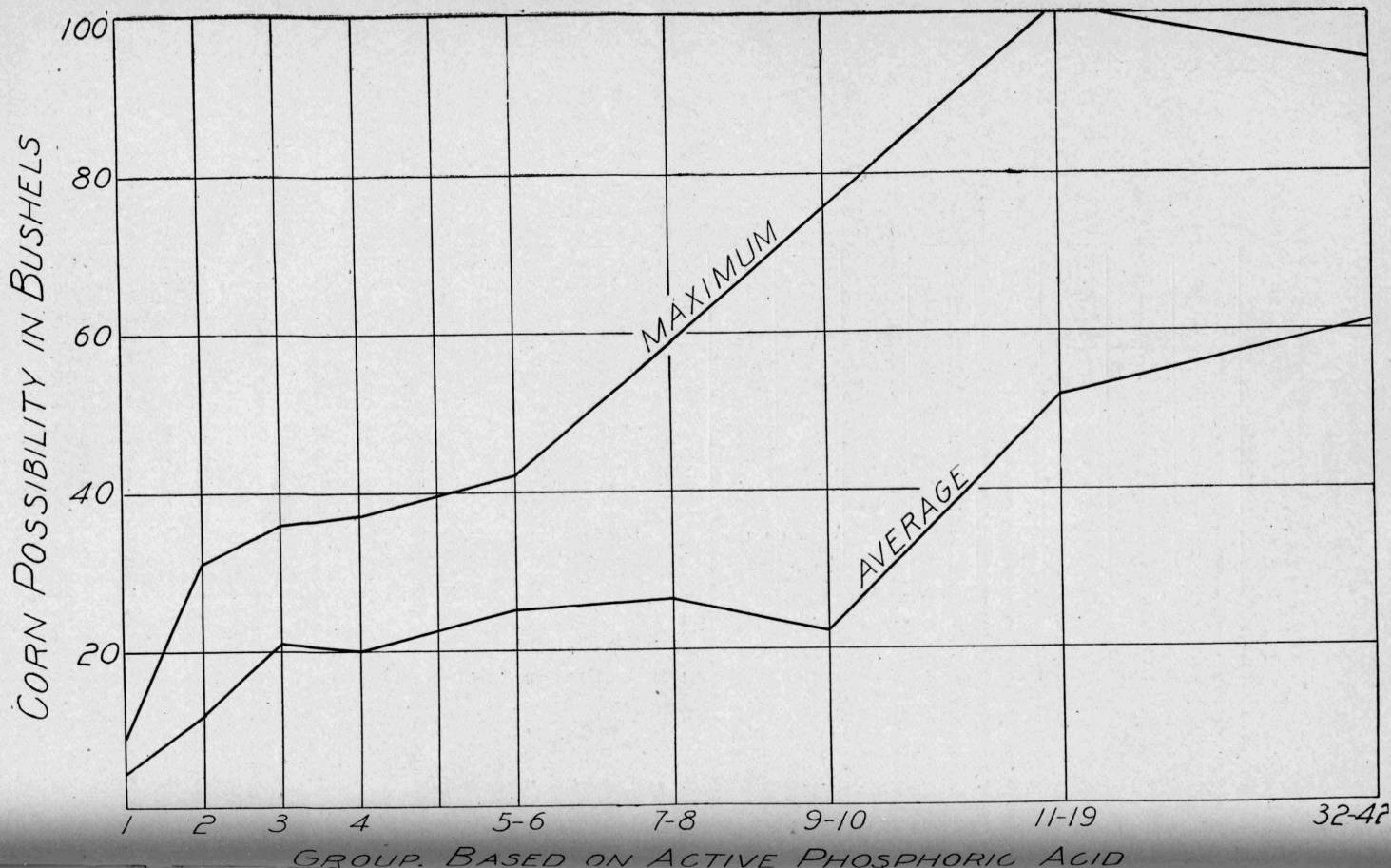
In Group 4-8, 1 soil, 982, would be raised considerably in rank by correction for fixation. It would appear from the above, that correction for fixation should not be made in applying the analyses of the soil to the results of pot experiments. We believe, however, that the fixation and acid consumed should be taken into consideration. The matter is worthy of further study.

TABLE NO. 27—Relation of "Acid Consumed" to Soil Deficiency.

	Groups.								
	1	2	3	4	5–6	7–8	9–10	11–19	32–42
Acid consumed—Number of soils:									
Low—below 5%	12	17	7	2	1	3	4	2	1
Medium—5–10%	1	4	4	0	2	2	0	1	0
High—10–25%	1	5	2	1	3	0	0	1	1
Very high—over 25%	1	2	4	4	2	9	4	4	4
Not given	0	1	1	0	0	1	0	0	0
Percentage consumed:									
Maximum	100	100	100	100	100	100	100	55	99.5
Minimum	0	0	0.9	0	3.0	2.0	1.0	4.0	2.0
Average	9.6	10.6	24.2	50.7	27.6	47.6	33.9	26.8	50.1
Percentage consumed by exceptional soils:									
DD	.....	.....	.....	1.9	6.1	6.1–7.5	1.	43	84.2–99.5
D	0–2	0–100	.....	.....	.....	.....	.....	.....	.....
S	.....	5	99	17.2	54.5–3.0	.....	3.3–25.3	.....	.....

TABLE NO. 28—Relation of Fixation to Soil Deficiency.

	Groups.								
	1	2	3	4	5–6	7–8	9–10	11–19	32—42
Number of soils:									
Very low—below 25%	4	8	6	1	1	2	2	2	1
Low—25–50%	6	4	2	1	2	5	0	1	3
Medium—50–80%	3	11	5	4	5	6	5	3	2
High—80–90%	1	5	3	1	0	1	0	1	0
Very high—90–100%	1	1	1	0	0	0	1	1	0
Not made	0	0	1	0	0	1	0	0	0
Percentage fixed:									
Maximum	86	87.5	87.1	86.7	74.2	82.0	97.6	96.9	72.4
Minimum	3.8	2.4	2.9	14.4	24.0	5.6	9.2	7.6	16.9
Average	44.3	51.1	48.3	57.1	52.5	48.1	56.8	56.1	43.6
Percentage fixed by exceptional soils:									
Very deficient	.....	.....	.....	14.4	43	53–51	98	61	48–29
Deficient	14–26	21–22–84	.....	.....	.....	.....	.....	.....	.....
Not definite	.....	63	68	72.6	68–59	.....	75–12	.....	.....


CORN POSSIBILITY IN BUSHELS
100
80
60
40
20
MAXIMUM
AVERAGE
1
2
3
4
5-6
7-8
9-10
11-19
32-42
GROUP. BASED ON ACTIVE PHOSPHORIC ACID

PHOSPHORIC ACID REMOVED BY CROPS.

In a number of the pot experiments shown in Table 23 we determined the phosphoric acid in the crop, and calculated from this the amount of phosphoric acid withdrawn from the soil which received no phosphoric acid.

Assuming that 40 bushels of corn requires 25 pounds of phosphoric acid, and a weight of 2,000,000 pounds of soil to the acre, we have calculated the number of bushels of corn which would be produced by the phosphoric acid withdrawn from the soil. One bushel of corn we estimate to require 0.00156 grams phosphoric acid per pot of 5000 grams of soil.

The results of these calculations are presented in Table 29, and a summary of results in Table 30. We find that the average possible corn crop increases regularly with each group, the only exception being Groups 9 and 10, containing 3 soils and 3 crops. Right here we must again call attention to the fact that these crops were grown under diverse conditions, and the climatic conditions were sometimes not favorable to the crop. But we feel that the relation between the average corn possibility and the quantity of active phosphoric acid in the soil is very significant.

The first two groups of soils, which are highly deficient in phosphoric acid, have an average possibility of 4.5 and 12.5 bushels of corn, respectively. Groups 3 to 10, the soils of which are prevailingly deficient in phosphoric acid, as we have pointed out, have an average corn possibility of 19.7 to 26.5 bushels of corn per acre—the variation is not large.

Group 11-19 and 32-42 have an average corn possibility of 50-60 bushels per acre.

We have already pointed out that a soil may be highly productive, and yet appear deficient in a pot experiment.

If we consider the *maximum* corn possibility within the groups, we find that, like the average corn possibility, it increases with the quantity of phosphoric acid extracted from the soil by N/5 nitric acid, with the exceptions of Groups 9-10 and 11-19. We find a maximum possibility of 31 bushels in Group 2, from 37 to 59 in Groups 3-10, and from 94 to 104 in Groups 11-12.

It appears that soils may provide sufficient phosphoric acid for large crops, and yet respond to applications of phosphatic fertilizers. The response may, however, vary with climatic conditions. We have already pointed out that the application of pot experiments to field conditions is a matter which we shall study.

TABLE NO. 29—Phosphoric Acid of the Soil.

Laboratory Number.		Deficiency.	Weight phosphoric acid in crop.	Equivalent to corn. Bu. per acre.	Availability. %	Series.	Crop.	Period of growth.
	Group 1:							
306	Susquehanna fine sandy loam	DD	.0078	5	19.2	I–06	Corn	4–18— 6– 8
310	Orangeburg fine sandy loam	DD	.0034	2	25.0	J–06	Corn	4–18— 6– 8
		DD	.0154	9	10	14–08	Corn	5–11— 7–31
336	Susquehanna fine sandy loam	DD	.0059	4	43.0	K–06	Corn	7–19— 9–10
819	Norfolk fine sandy loam	DD	.0103	7	34.0	L–07	Corn	5–11— 8– 5
821	Orangeburg fine sand	DD	.0044	3	17.0	L–07	Corn	4– 6— 7– 6
		DD	.0050	3	20	14–08	Corn	5–12— 8– 2
828	Norfolk fine sand	DD	.0144	9	36	L–07	Corn	4–17— 6–11
850	Susquehanna sandy loam	DD	.0050	3	16	M–07	Corn	5– 1— 6– 9
	Average			4.5	27			
316	Norfolk fine sandy loam	DD	.0040	3	14.8	J–06	Corn	4–18— 6– 8
324	Houston loam	DD	.0320	21	64	K–06	Corn	7–19— 9–10
	Group 2:							
314	Norfolk fine sand	DD	.0053	4	6.5	I–06	Corn	4–18— 6– 8
334	Houston loam	DD	.0476	31	87.0	K– 06	Corn	7–19— 9–10
340	Susquehanna fine sandy loam	DD	.0138	9	23.0	K–06	Corn	5–11— 8– 5
816	Laredo fine sand	DD	.0129	8	21	L–07	Corn	4– 6— 6–11
817	Lufkin fine sandy loam	DD	.0225	15	41.0	L–07	Corn	4– 6— 7– 6
834	Orangeburg fine sandy loam	DD	.0170	11	29	M–07	Corn	4–17— 6–14
843	Wabash heavy clay	DD	.0190	12	27	M–07	Corn	5–11— 8– 5
859	Norfolk fine sand	DD	.0180	12	19	M–07	Corn	5– 3— 7– 6
1586	San Jacinto clay	D	.0195	13	27	26–08	Mustard	9–15—11– 3
1588	Lufkin sandy loam	D	.0174	11	23	26–08	Mustard	9–15—11– 3
1583	Houston gravelly clay S. S.	D	.0205	13	29	26–08	Mustard	9–15—11– 3
1585	Willis sand S. S.	D	.0270	18	30	26–08	Mustard	9–15—11– 3
	Average			12.5	28.8			
1126	Winfield fine sand, S. S.	DD	.0073	5	12	11–08	Corn	4–30— 6–23
	Group 3:							
829	Houston loam	D	.0549	36	52	L–07	Corn	4–17— 6–19
832	Orangeburg clay	DD	.0070	4	6.0	M–07	Corn	4–17— 6–14
860	Orangeburg fine sand	DD	.0030	19	2.8	M–07	Corn	5– 3— 7– 6

TABLE NO. 29—Phosphoric Acid of the Soil—continued.

Laboratory Number.		Deficiency.	Weight phosphoric acid in crop.	Equivalent to corn. Bu. per acre.	Availability. %	Series.	Crop.	Period of growth.
1123	Winfield fine sandy loam	D	.0460	30	38	11–08	Corn	4–27— 6–18
1594	Houston black clay, S. S	D	.0210	13	14	26–08	Mustard	9–15—11– 3
1578	San Antonio clay loam, S. S	S	.0351	23	29	26–08	Mustard	9–15—11– 3
	Average			20.8	31.2			
	Group 4:							
172	Norfolk sand	DD	.0087	6	5.5	I–06	Corn	5–12— 8– 2
		DD	.0180	12	9.0	14–08	Corn	5–11— 8–15
330	Crawford stony clay	D	.0570	37	39.0	K–06	Corn	7–19— 9–10
328	Blanco loam	DD	.0383	24	23.0	K–06	Corn	7–19— 9–10
1582	Houston gravelly clay	D	.0204	13	13	26–08	Mustard	9–15—11– 3
1577	San Antonio clay loam	D	.0418	27	21	26–08	Mustard	9–15—11– 3
910	Houston black clay	D	.0308	20	17	30–08	Mustard	10–11—12–18
	Average			19.7	18.4			
	Groups 5 and 6:							
133	Sanders loam	DD	.0134	9	5.6	I–06	Corn	4–18— 6– 8
127	Houston black clay	D	.0324	28	17.6	J–06	Corn	4–18— 6– 8
830	Laredo gravelly loam	S	.0261	17	13.0	L–07	Corn	4–17— 7– 6
851	Wilson clay loam	D	.0660	42	25.0	M–07	Corn	5– 1— 6–19
940	Wilson loam	S	.0460	29	17.0	31–08	Mustard	10–22—12–18
	Average			24.4	14.4			
134	San Antonio clay loam	D	.0337	22	8.0	7–06	Corn	4–18— 6– 8
	Groups 7 and 8:							
211	Probably Norfolk sand or fine sand	D	.0102	7	3.7	J–06	Corn	4–16— 6– 8
818	Wabash fine sandy loam	D	.0923	59	28	L–07	Corn	9–11—11– 2
833	Laredo fine sandy loam	D	.0740	48	21	M–07	Corn	4–17— 6–11
1134	Norfolk fine sand, S. S	D	.0360	23	14	11–08	Corn	4–30— 6–23
		D	.0294	19	8	31–08	Mustard	10–22—12–18
982	Cameron clay S. S	D	.0574	37	16	13–08	Corn	5– 7— 6–23
		S	.0324	21	9	31–08	Mustard	10–22—12–18
1205	Houston loam S. S	D	.0250	16	8	13–08	Corn	5– 7— 6–23

TABLE NO. 29—Phosphoric Acid of the Soil—continued.

Laboratory Number.		Deficiency.	Weight phosphoric acid in crop.	Equivalent to corn. Bu. per acre.	Availability. %	Series.	Crop.	Period of growth.
1581	Houston black clay loam S. S	D	.0256	17	7	26-08	Mustard...	9-15—11- 3
1593	Houston black clay	D	.0619	39	11	26-08	Mustard...	9-15—11- 3
1598	Yazoo sandy loam S. S	D	.0214	14	6	26-08	Mustard...	9-15—11- 3
1600	Houston black clay S. S	S	.0394	25	11	26-08	Mustard...	9-15—11- 3
1597	Yazoo sandy loam	D	.0303	19	10	26-08	Mustard...	9-15—11- 3
	Groups 9 and 10:							
318	Lufkin fine sand	D	.0131	7	3.0	J-06	Corn.....	5- 7— 6-23
338	Yazoo clay	D	.0312	20	7.9	K-06	Corn.....	7-19— 9-10
1133	Norfolk fine sand	S	.0608	39	13	9-08	Corn.....	4-22— 6-18
	Groups 11 to 19:							
182	Yazoo clay	D	.0085	6	1.3	J-06	Corn.....	4-18— 6- 8
		S	.1000	64	14	30-08	Mustard...	10-16—12-18
845	Wabash silt loam	S	.1580	101	25	M-07	Corn.....	5- 1— 6-19
1202	Houston clay	D	.0825	53	8	11-08	Corn.....	4-30— 6-23
1595	Austin clay	D	.0580	38	7	26-08	Mustard...	9-15—11- 3
	Average			52.5	11.1			
	Groups 32 to 42:							
827	Laredo silt loam	DD	.0142	9	8	L-07	Corn.....	4- 6— 6-11
931	Laredo silty clay	D	.1440	92	7	M-07	Corn.....	4-17— 7- 6
		S	.0880	57	4	14-08	Corn.....	5-11— 8- 5
938	Austin fine sandy loam	S	.1131	73	5.4	14-08	Corn.....	5-11— 8- 5
942	Bastrop sandy loam	S	.1460	94	7.0	14-08	Corn.....	5- 2— 8- 2
934	Wabash clay	S	.0617	39	3.9	30-08	Mustard...	10-11—12-18
	Average			60.7	4.7			

TABLE NO. 30—Average Corn Possibility and Availability of Phosphoric Acid

	Corn equivalent (bu. per acre)		Availability percentage	
	Average.	Maxima.	Average.	Maxima.
Group 1—9 soils, 11 crops	4.5	9	27.0	43
Group 2—13 soils, 13 crops	12.5	31	28.8	87
Group 3—6 soils, 6 crops	20.8	36	31.2	52
Group 4—6 soils, 7 crops	19.7	37	18.4	39
Groups 5 and 6—6 soils, 6 crops	24.4	42	14.4	25
Groups 7 and 8—13 soils, 13 crops	26.5	59	11.7	28
Groups 9 and 10—3 soils, 3 crops	22.0	39	7.9	13
Groups 11-19—4 soils, 5 crops	52.5	101	11.1	25
Groups 32-42—5 soils, 6 crops	60.7	94	4.7	7

AVAILABILITY OF ACTIVE PHOSPHORIC ACID.

Assuming that the phosphoric acid removed by the crop comes from the phosphoric acid extracted by N/5 nitric acid, we can calculate the percentage of phosphoric acid taken up by the crops from the data given in Table 23. These calculations have been made, and the results are presented in Table 29, a summary being given in Table 30. We term the percentage of the active phosphoric acid taken up by the crop, its availability. We do not wish to say, however, that the phosphoric acid taken up does not come from sources other than that soluble in N/5 nitric acid.

Considering first the average availability, we find it rises from 27 to 31.2 in the first three groups. This rise, however, is of little significance—we can almost say that the average availability is the same for the three groups.

If the phosphoric acid dissolved by N/5 nitric acid comes from the natural phosphates of lime, we can not expect them to have a high availability. An average availability of 27-31 per cent for the phosphoric acid of the first three groups must lead to the conclusion that some of the phosphoric acid taken from the soil comes from other sources than that soluble in N/5 nitric acid. In other words, the assumption we started with is not justified, at least in these three groups of soils.

The first group of soils, those containing less than ten parts per million of active phosphoric acid, probably does not contain any phosphate of lime at all. The 7-10 parts per million of phosphoric acid dissolved represents the solution of a portion of some highly insoluble phosphate. The availability of the phosphates based upon the portion dissolved, is thus increased. The availability should be based upon the total quantity of the insoluble phosphate, which is not known.

The considerations which apply to Group 1 also apply to the other groups, their importance decreasing with the grade of the group. In other words, some of the phosphoric acid withdrawn by crops comes from the less soluble phosphates. It is, of course, possible that other phosphates of importance may be present in the soil. This is apparent when we consider the high maximum availability of the active phosphoric acid in the different groups.

While not decreasing regularly, the percentage availability decreases with the grade of the group. This decrease may be because the assumption is incorrect, that the phosphoric acid withdrawn comes entirely from the N/5 nitric acid extract. It is possible that the availability in the higher groups represents more nearly the availability of the active phosphoric acid, than that in the lower groups.

The matter of the availability of the phosphoric acid of the soil is being subjected to further study.

SUMMARY AND CONCLUSIONS.

1. The plant food withdrawn from the soil by the plant depends upon the form of combination of the plant food, its protection or non-protection by encrusting particles, the action of weathering agencies upon it, and the nature of the plant.

2. The composition of the soil extract, by any solvent, depends upon the quantity of the phosphate exposed to the solvent, and its solubility under the conditions of the extraction, the solubility of the material which protects phosphates, and the fixing ability of the soil for phosphoric acid from the solvent in question.

3. Fifth-normal nitric acid dissolves phosphates of lime completely, but dissolves such iron and aluminium phosphates as usually occur in the soil only to a slight extent. It thus distinguishes between these two classes of compounds in the soil.

4. Fifth-normal nitric acid may not distinguish between phosphates which have unequal values to plants. Soils should be compared which probably contain the same kinds of phosphates.

5. One per cent citric acid has a lower solvent power for mineral phosphates than fifth-normal nitric acid. The solvent powers of other solvents is discussed. Fifth-normal nitric acid is preferred.

6. Soils absorb phosphoric acid in solution in fifth-normal nitric acid, and other solvents.

7. The percentage of the added phosphoric acid absorbed by the soil increases as its content of oxides of iron and aluminium increases.

8. Residues from the extraction of the soil with fifth-normal

nitric acid and with stronger acids, may have nearly as great absorbing power as the original soil.

9. The phosphoric acid absorbed by soils is not extracted by the first extraction with fifth-normal nitric acid, but its effect is evident in the fourth, and sometimes in the sixth, extraction.

10. Natural soils resemble soils which have received potassium phosphate in their behavior to fifth-normal nitric acid in successive extractions.

11. Soils containing little or no phosphates of high solubility give practically the same amounts of phosphoric acid to successive extractions.

12. Soils which have a fixing power of 80 per cent or less, have a fixing power of about half as much from N/5 nitric acid solution. Soils which have a fixing power over 80, may fix equally as high a percentage from fifth-normal nitric acid.

13. When the significance of the phosphoric acid extracted from a soil by fifth-normal nitric acid is to be decided, the fixing power of the soil for phosphoric acid, and the acid consumed, should also be known.

14. Sulphate of lime increases the amount of phosphoric acid extracted from soils high in iron.

15. Calcareous soils contain phosphates which are protected by the carbonate of lime from the roots of plants, but which are exposed by solution of the carbonate of lime in acid solvents.

16. The amount of lime and magnesia dissolved may be estimated from the quantity of acid consumed.

17. The quantity of material dissolved in second or succeeding extractions with acid is sometimes large.

18. It would appear that the lime and magnesia are present in highly soluble forms (carbonates and silicates), moderately soluble silicates and silicates of low solubility.

19. Citric acid dissolves less iron, lime and magnesia, than fifth-normal nitric acid.

20. It would appear that the phosphoric acid dissolved by fifth-normal nitric acid in excess of about ten parts per million comes from phosphate of lime.

21. Judging the amounts of phosphates of lime presented to the roots of plants in a given soil, one must allow for the decrease due to absorption, and the increase due to solution of incrusting material, so far as possible.

22. The author extracts the soil with fifth-normal nitric acid without correcting for neutralization.

23. It is impossible to maintain only one variable in pot experiments, though one may predominate. Soils may appear de-

ficient for phosphoric acid and yet be highly productive without phosphatic fertilizing.

24. Soils containing less than 20 parts per million of phosphoric acid extracted by fifth-normal nitric acid are highly deficient in phosphoric acid in pot experiments.

25. Soils from which 20 to 100 parts per million of phosphoric acid are extracted by fifth-normal nitric acid are usually deficient for phosphoric acid in pot experiments, and the extent of their deficiency is related to the quantity of phosphoric acid present.

26. Although the pot experiments were carried out under diverse conditions, the average corn crop is closely related to the quantity of active phosphoric acid in the soil.

27. Soils containing from 100 to 200 parts per million of active phosphoric acid are possibly deficient in phosphoric acid in pot experiments, the chances being even that they are or are not deficient.

28. The average possible corn crop, based upon the quantity of phosphoric acid extracted from the soil in pot experiment, increases regularly with the amount of active phosphoric acid extracted by fifth-normal nitric acid.

29. Soils containing less than 10 parts per million of phosphoric acid had an average possibility of 4.5 bushels corn per acre. If they contained 10 to 20 parts, the possibility is 12.3 bushels. If they contained 30 to 100 parts, the average possibility is 19.7 to 26.3 bushels corn per acre. If they contained 110-420 parts per million, the average possibility was 50-60 bushels corn per acre.

30. The maximum possible corn crop also increases directly with the quantity of active phosphoric acid in the soil.

31. Soils may provide sufficient phosphoric acid for large crops, and yet respond to phosphoric fertilization in pot experiments.

32. Phosphoric acid is taken up by the crop which comes from other sources than the active phosphoric acid—especially if the soil contain less than thirty parts per million of active phosphoric acid.

33. The phosphoric acid removed by the crop in percentages of the active phosphoric acid, decreases with the quantity of active phosphoric acid in the soil.

Special mention should be made of the services of Mr. E. C. Carlyle in connection with the work here reported.